THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

CRYPTON EQUIPMENT LIMITED
BRIDGWATER SOMERSET ENGLAND

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON ONE

BASIC PRINCIPLES OF ENGINE OPERATION

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

BASIC PRINCIPLES OF ENGINE OPERATION

Modern engines operate on the well known four-stroke principle. The engine develops power only during the power stroke. The remaining three strokes are all in the nature of being preparatory to or "cleaning up" after this important instant.

It will be convenient to take a single cylinder as an illustration and assume that the moving parts - crankshaft, flywheel, connecting rod, piston, camshaft and valves - are in motion from the momentum imparted to the flywheel by the previous power impulse. The four strokes of the engine can then be defined as follows:-

Intake (Fig.1)

We start with the piston at the top of the cylinder as shown in Fig.1. Only a small space, the COMBUSTION CHAMBER, is left above the piston when at the top of its travel. This position of the piston is called TOP DEAD CENTRE. The inlet valve is opened and the exhaust valve is closed. As the piston moves down the cylinder, space is increasingly created between the piston crown and the cylinder head. This reduces the normal air pressure within the combustion chamber and creates an area of pressure lower than the outside atmospheric pressure. The higher outer pressure forces air in through the carburettor which picks up vaporised fuel, the mixture of air and fuel flowing past the throttle valve which is partly open, into the manifold and - into the cylinder via the open valve.

When the piston is at the bottom of its stroke - BOTTOM DEAD CENTRE - the cylinder is said to be full of the fuel-air mixture. The inlet valve is now closed. The crankshaft will have revolved 180 degrees.

Compression Stroke (Fig.2)

At the completion of the intake stroke when the cylinder is completely filled with air-fuel, the inlet valve closes and the piston rises as shown in Fig.2. The trapped gas is progressively squeezed up into the decreasing space between the piston crown and the cylinder head. At the start of this stroke any remaining low pressure or "vacuum" is quickly cancelled as the pressure first rises to that of the atmospheric and then increases above it in proportion to the reduction of the volume until the compression pressure of the air-fuel reaches its maximum at the uppermost position of the piston. The crankshaft will now have revolved 360 degrees.

The Power Stroke (Fig.3)

At about the time the piston reaches the top of its second stroke, the compressed mixture is ignited by the spark at the spark plugs as shown in Fig.3.

When a combustible mixture is compressed and ignited it will develop many times the

FIG.1.

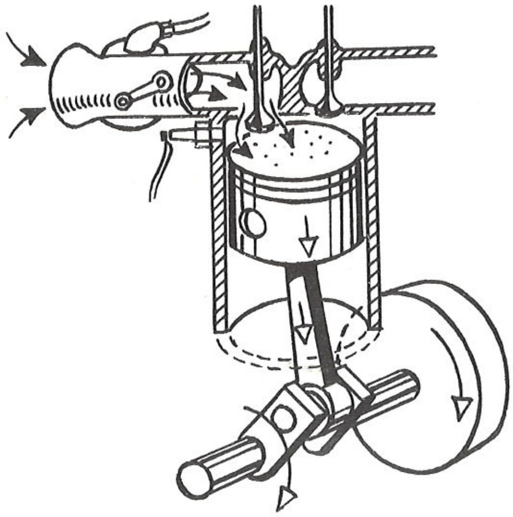


FIG.2.

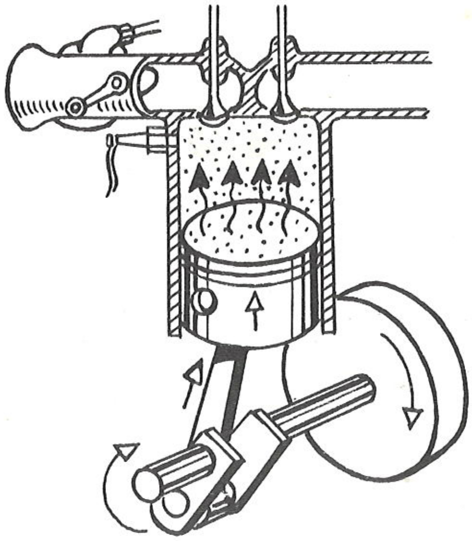


FIG.3.

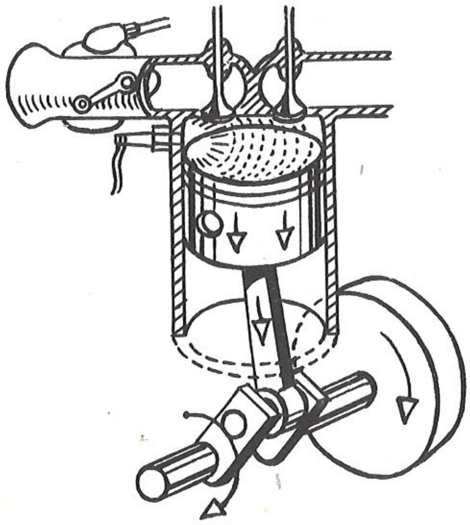
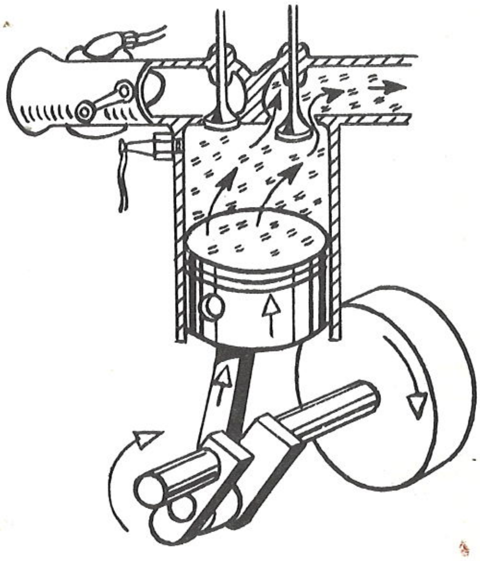


FIG.4.



pressure than would be the case if it were not compressed. The actual pressure is approximately four times the maximum compression pressure and the thrust of this pressure forces the piston down. The higher the extent to which the mixture is compressed the higher the pressure developed when it is burned. It is therefore important to compress the mixture to the highest extent possible to get the maximum power from an engine.

When the compressed mixture is ignited it burns very rapidly and the temperature of the burning gases reaches a very high figure - about 4,000 degrees F. which results in an extremely high pressure. This high pressure is applied to all parts of the chamber, the cylinder head gaskets and piston. Since the piston is the only part that can move, it is pushed downwards to the bottom of its travel. The crankshaft has now revolved one and a half times - 540 degrees.

Exhaust Stroke (Fig.4)

The piston now travels upwards again as shown in Fig.4. The exhaust valve is opened and the burned gases are swept through this valve into the exhaust line, whence it is discharged into the atmosphere. The exhaust valve is closed and we are ready to start all over again. The crankshaft has revolved twice, namely, 720 degrees.

SUMMARY.

(1) The INTAKE STROKE draws combustible mixture into the cylinder.

(2) The COMPRESSION STROKE compresses this mixture and places the crankshaft in a position to receive power.

(3) The POWER STROKE burns the compressed mixture and the high pressure generated by the expanded gases pushes the piston down, applying power to the crankshaft.

(4) The EXHAUST STROKE scavenges the fuel from the cylinder and returns the piston to its top position ready for a repeat of the four-stroke cycle.

To keep the essentials of the engine in our mind we have only to remember four words:-

INTAKE - COMPRESSION - POWER - EXHAUST.

The crankshaft receives one power stroke in two revolutions. To keep it turning steadily between power strokes a flywheel is fitted. The intake and exhaust valves open and close once every cycle. Valve gear camshaft revolves at half crankshaft speed. Only one spark per cycle is needed and the distributor also runs at half crankshaft speed.

FACTORS GOVERNING ENGINE EFFICIENCY.

The simple engine we have considered has equal phases of crankshaft rotation for each stroke ... intake 180 degrees ... compression 180 degrees ... power 180 degrees and exhaust 180 degrees. This simple engine will run but will not develop anything like

FIG. 5.

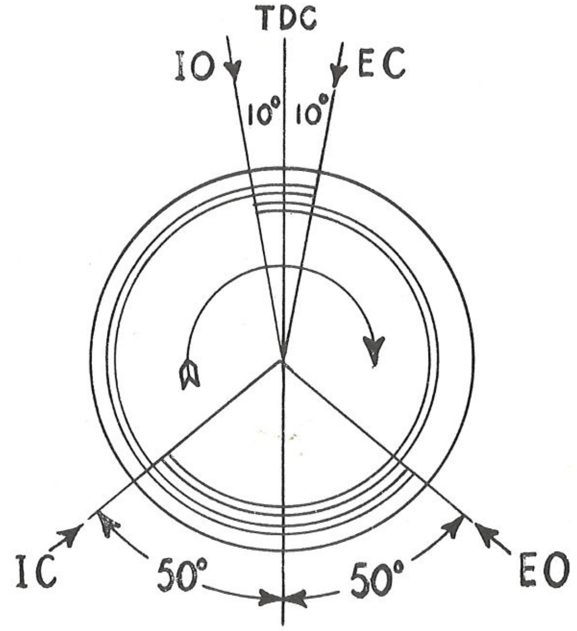

TDC
IO
EC
10°
10°
IC
50°
50°
EO

FIG. 5A.

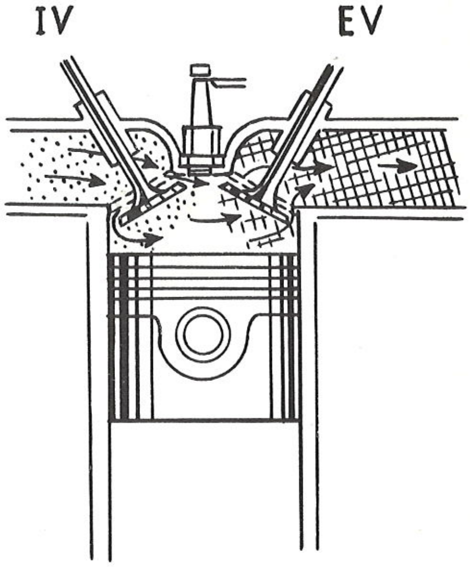


FIG. 6.

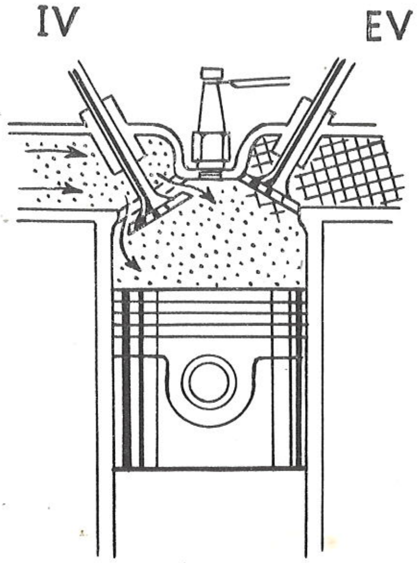


FIG. 7.

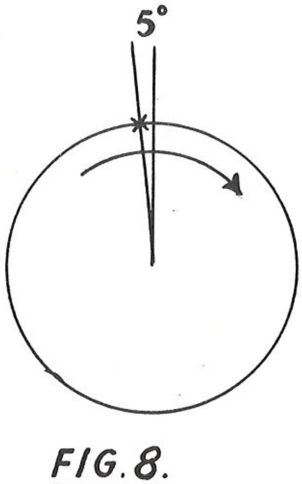


FIG. 8.

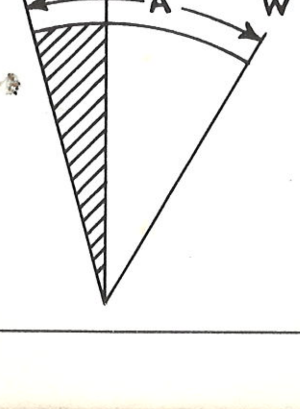
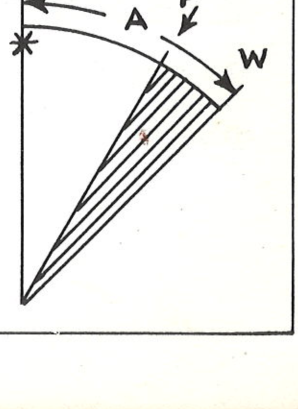


FIG. 9.



the power obtained from modern engines. To get maximum power many modifications are needed.

As the piston moves down at high speed on the intake stroke, the mixture does not have time to fill the cylinder. To correct this the intake valve is held open longer so that more mixture can enter the cylinder. This increases the amount of chemical energy (heat) fed into the engine and consequently also increases the mechanical energy developed. On the exhaust stroke it is essential that the cylinder is exhausted as completely as possible. To ensure this the exhaust valve is kept open longer.

The valve timing diagram of a modern engine is shown in Fig.5 and supplementary notes are attached to this lesson for the benefit of those readers who desire to obtain a thorough understanding of the importance of valve timing phases in the modern engine. The remaining diagrams, Figs 5A - 6 - 7 - 8 and 9 are also referred to in these supplementary notes.

For maximum efficiency the cylinder needs to be charged with the maximum amount of combustible mixture. In other words, the engine must BREATHE IN the biggest possible amount of mixture. Also the exhaust gases must be purged as completely as possible to permit a full fresh charge to enter. Any burned gases left in the cylinder on the exhaust stroke will dilute the incoming mixture. In other words, the engine must BREATHE OUT to the maximum extent possible.

The degree of efficiency with which the engine breathes is called VOLUMETRIC EFFICIENCY. If the engine were completely charged on every intake stroke, it would have 100 per cent. volumetric efficiency. This is not attained in service but continuous improvements in intake and exhaust valve timing and valve design have considerably improved volumetric efficiency and contributed to the important improvements in performance obtained with modern engines.

The importance of volumetric efficiency is demonstrated every time the car is driven on the road. When, on a level road, the throttle is held wide open, more mixture is fed to the engine, its volumetric efficiency is increased and the engine generates increasing power to accelerate to higher and higher speeds. As the required speed is reached the throttle is closed until this speed is retained. This restricts the flow of mixture, reduces the volumetric efficiency and reduces power. The amount of fuel is reduced to that needed to propel the car at the speed required. An engine may be capable of developing 60 or 80 horsepower at a given speed with the throttle opened. As the throttle is closed the breathing power of the engine is reduced until it develops 30, 10 or even 2 or 3 H.P. At idling speeds the engine develops only enough power to keep it turning over.

Volumetric efficiency varies with engine speeds. It is higher at slow than at high speeds. This is due to the effect of friction on the flow of the gas. At low speed and open throttle the intake stroke occurs less frequently than at high speed. Also less gas is required at slow speed ... the speed of gas flow through the manifolds, valve ports, air cleaner, etc. is slower. The friction is reduced and less pressure is needed to push the gas along. Therefore, more combustible gas gets into the engine and more burned gases will get out.

The following factors are important in determining volumetric efficiency:-

(1) Valve size and lift.
(2) Valve port size
(3) Intake and exhaust manifold design.
(4) Carburettor design.
(5) Air cleaner restriction.
(6) Silencer and exhaust restriction.

The nett result of improved volumetric efficiency is that IT GETS MORE FUEL INTO THE ENGINE.

As a service man there is not a great deal you can do in improving volumetric efficiency. There is nothing practical that can be done to alter valve timing, manifold, air cleaner and silencer design. You can, however, be careful to see that air cleaners and silencers are not causing excessive restriction.

COMPRESSION AND POWER.

Only a small percentage of the potential energy in the fuel burned in an engine is converted into mechanical power. There is enough energy in one gallon of petrol to propel a car travelling at 30 miles an hour for over two hundred miles. The problem is how to convert as much of this energy as possible into power.

One way in which this can be done is by compressing the mixture of petrol and air to the maximum possible extent. The pressure developed by burning the mixture is approximately four times the compression pressure. If we compress the mixture to 100 lb. per square inch and then ignite it the pressure developed will be about 400 lb. per square inch. This is equivalent to a total pressure of about two tons on the top of a piston 3½" diameter. The higher the mixture can be compressed the greater will be the power developed. If we compress the mixture in an engine to 150 lb. per square inch before ignition we will get much greater power than if the mixture were compressed to only 100 lb. per square inch.

Therefore, to increase the power output of a given engine it must have as high a compression ratio as possible. This is achieved by reducing the space above the piston when it is at the top of its stroke. When this is done we increase the ratio between the volume of the entire cylinder in relation to the volume of the combustion chamber. This ratio is called the Compression Ratio. If we suppose that the cylinder and combustion chamber holds six volumes when the piston is at the bottom dead centre and only one volume when the piston is at top dead centre, then the compression ratio of the engine is 6 : 1.

It is natural to ask - "Why not increase compression ratios to really high figures - up to 10 : 1 or even 50 : 1?" The reason why this is not done is that if the pressure becomes too high the mixture does not burn correctly and power is wasted. The problem of detonation develops which is something we shall consider a little later.

We see, therefore, that to make an engine of a given size more powerful we -

(1) Increase the volumetric efficiency which has the effect of putting more fuel or heat into the engine.

(2) Increase the compression ratio which converts more of the potential energy in the fuel to mechanical power.

CREATION OF INDUCTION VACUUM.

The principle governing the creation of vacuum or low pressure in the cylinder and induction space is illustrated in the model shown in Fig.10. This comprises a cylinder "C" having a pipe "M" which is nearly closed by the valve "V". The piston "P" is connected through the rod "R" to the handle "H" by which it can be drawn out. Air pressure is uniform both within and without the cylinder until the handle is pulled down in the direction shown by the large arrow. Every inch of piston motion creates so many more cubic inches of space within the cylinder and pipe so that the air in this space becomes "spread out" or rarified and the pressure drops below that of the outside atmosphere.

Outer air pressure will force air past the nearly-closed valve at "AP" at a fixed number of cubic inches per minute. If the piston is held in an extended position internal pressure will be gradually restored in proportion to the rate of leak-in past the valve. If we continue to pull the piston out the creation of more space will prevent the rate of leak-in catching up with the cubic capacity added and the low pressure or partial vacuum will be sustained. In pulling out the handle a spring effect is felt due to the air pressure "L" at the back of the piston.

There is a definite relationship between the rate of leak-in and the rate of space created by the movement of the piston.

(1) If the fixed rate of leak-in is equal to or greater than the displacement rate, no vacuum will be created - merely a flow of air into the cylinder following the piston.

(2) Pressure commences to drop in the cylinder, i.e., a vacuum is created as soon as the displacement rate becomes greater than the leak-in rate.

(3) The lowest pressure or highest vacuum in the cylinder exists when a nearly closed valve restricts the leak-in to a minimum and high piston speed produces a maximum displacement rate.

If we apply the principle described to the induction system of a single cylinder engine, the inlet pipe or manifold is open to the cylinder only while the inlet valve is held off its seat. The induction vacuum will, therefore, occur in a series of waves, synchronous with camshaft rotation.

With 4, 6, or 8 cylinders supplied through a common manifold, the induction phases will overlap and there will be intervals during which two inlet valves will be open at the same time. Instead of a jerky fluctuation of vacuum, a more steady level will be maintained, varying only with the overlap intervals. This is shown in the diagram in Fig.11 where the vertical divisions show the four piston strokes at a, b, c and d with numbers indicating the cylinders of a 4-cylinder engine having a firing sequence of 1, 3, 4, 2. The diagram shows that No.3 inlet valve opens 10 degs. before No.1 piston reaches bottom centre and remains open after the closing of No.1 inlet at 50 degrees up the (b) stroke. The same overlap occurs between each pair of successively firing cylinders. The overlap intervals are indicated at "OL" and the one-valve open periods at 1X, 2X, 4X and 3X.

FIG. 10.

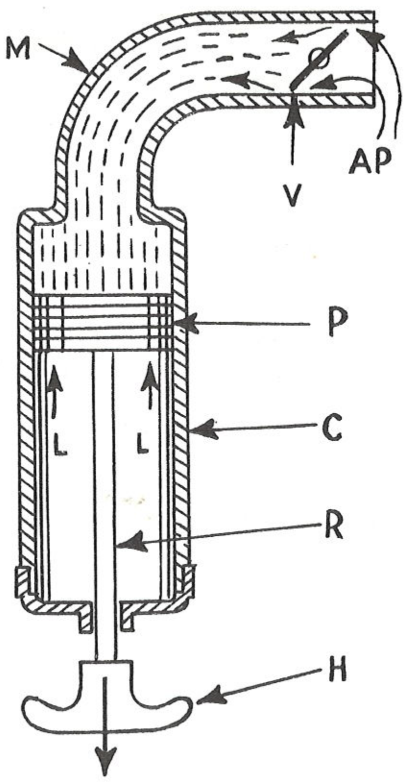

M
AP
V
P
L
L
C
R
H

FIG. 11.

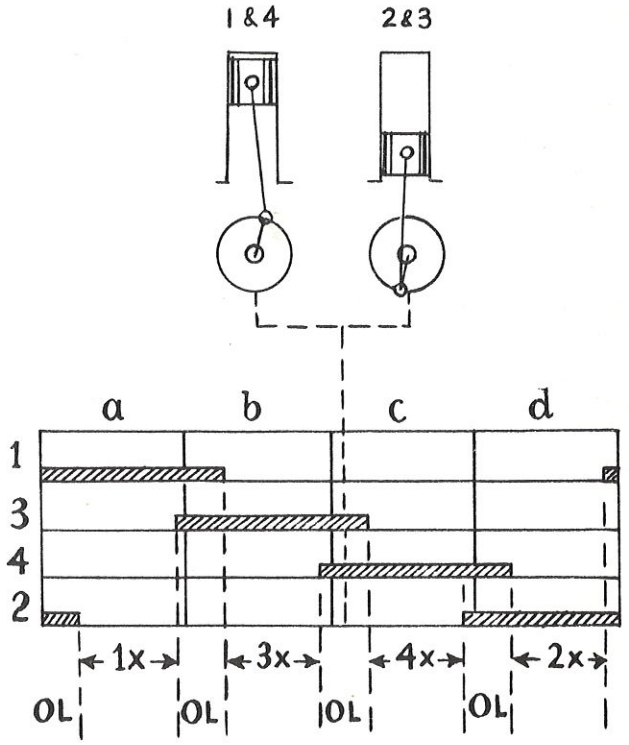

1&4
2&3
a
b
c
d
1
3
4
2
1x
3x
4x
2x
OL
OL
OL
OL

FIG. 12.

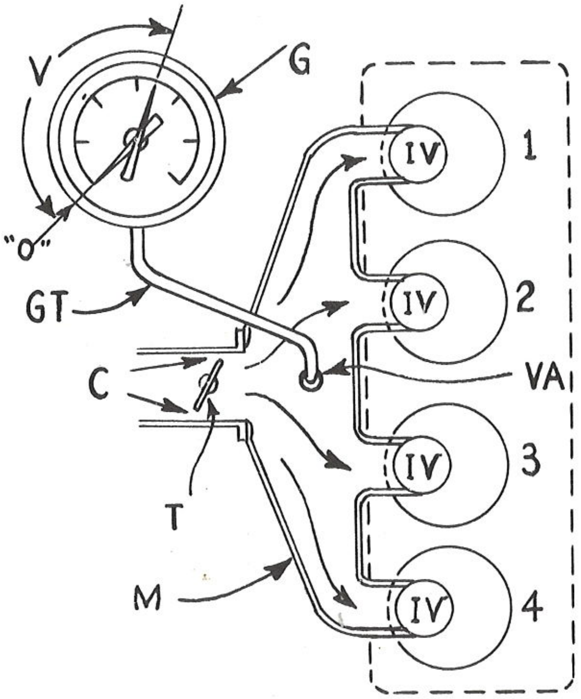
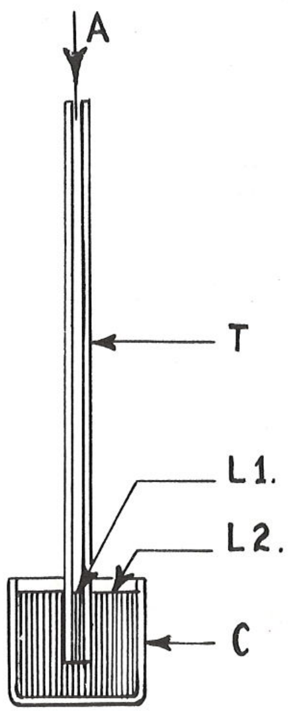

V
G
"O"
GT
C
T
M
VA
IV
IV
IV
IV
1
2
3
4

FIG. 13.



SUPPLEMENTARY NOTES RE VALVE TIMING CHARACTERISTICS.

The valve timing phases of a modern engine can be expressed in either of two ways. One is a statement of the opening and closing points of the inlet and exhaust valves in any one cylinder, such as the following:-

Inlet opens ... 10 deg. B.T.D.C.   Inlet closes ... 50 deg. A.B.D.C.

Exhaust opens .. 50 deg. B.B.D.C.   Exhaust closes ... 10 deg. A.T.D.C.

The second method is simpler and easier to understand, as it portrays graphically what happens during the complete cycle.

Fig.5 illustrates a timing diagram of this type. A circle, which represents crank rotation, has radial lines marking the opening and closing positions, and the two double-line sectors within the circle illustrate the valve-open periods. The inner sector (inlet valve) commences at a point 10 deg. before top dead centre, at I.O. and continues to a point at I.C. which is 50 deg. after bottom dead centre.

These points are piston positions in the stroke, and the shape of the sector shows that the valve opens before the top and closes after the bottom to the extent indicated. The outer sector, (Exhaust Valve) extends from a point 50 deg. before bottom dead centre and continues to a point 10 deg. after top dead centre. In this example, therefore, each valve remains open for an equal number of crankshaft degrees - 240 - but this is not always the case.

In studying this diagram we have to remember the sequence of phases. The beginning of induction follows the end of exhaust, and we can see how the exhaust valve does not completely close until the inlet valve has been open for 20 deg. The apparent overlap about bottom dead centre does not actually occur, as the compression and power phases take place between the closing of the inlet valve at I.C. and opening of the exhaust valve at E.O.

VALVE TIMING PHASES.

The basic four-cycle sequence is employed in all vehicle engines, other than those of two-stroke" design. The high-efficiency performance of which modern engines are capable, and the high speeds at which they commonly develop their maximum power, necessitates careful design in the matter of valve phases, opening and closing instants, and the rate at which each valve opens or closes.

If you examine the valve timing diagram of a modern engine, such as is shown in Fig.5 you will see that the opening and closing points do not coincide with the ending of piston strokes. The principle reason for this lies in the fact that a moving body of gas, like a liquid, has some weight, and therefore is subject to momentum and inertia. In everyday terms this means that a fast-moving column of gas cannot be suddenly stopped, neither can it be suddenly started in motion from a stand-still. Good use can be made of this tendency of a moving column of gas to continue moving, and even to act as a sort of piston in the pipe in which it is moving, as we shall see by examining the valve phases shown.

Starting at the commencement of the power cycle, the spark has just ignited the gas compressed in the combustion chamber, and the piston is starting its down stroke. When the piston is about two-thirds of the way down (130 deg. of crank rotation) the power thrust has practically expended its energy, and the crank is moving into an angle where piston pressure can no longer exert useful turning force on it. The exhaust valve therefore opens, at a point 50 deg. short of bottom centre, and burnt gas escapes, being pushed out by the rising piston on its up stroke.

You will see that the valve remains open from the point EO, and is still open, or rather is starting to close, when the inlet valve starts to open at the point IO, which is 10 deg. short of top centre. The exhaust finally closes at EC - 10 deg. after top centre. For a period equal to 20 deg. of crank rotation, therefore, both valves are open. What happens during this period is important. On the face of it, you might think the fuel gas would pass straight across the cylinder and follow the exhaust gas out of the open valve port. That is certainly its tendency, due to the momentum and extractor pump effect of the exhaust stream. What actually happens is shown in Figs. 5A and 6.

In Fig.5A the fuel gas stream (dotted area) is entering as the inlet valve IV opens, and the exhaust stream (shaded area) is passing out. This means that both valves can remain open while fuel gas follows up and replaces the departing residue, but the exhaust valve EV must close before fuel gas has time to enter the exhaust line.

Fig.6 shows how the closing of the exhaust valve ensures this, by trapping the new gas charge in the cylinder as the old residue is practically all removed.

The final point we observe is the continuation of the inlet valve opening beyond the bottom centre position. The valve finally closes at the position IC in Fig. 5, when the piston is about one third of the way up the compression stroke. This would appear to arrest the inflow of fuel gas and start to force it out again into the inlet manifold. The reason why this does not happen is the low pressure during the induction phase.

At bottom centre the inflow continues, as external air pressure is still trying to catch up on the state of vacuum within, and the first 50 deg. of crank rotation beyond bottom centre allow the internal pressure to rise to atmospheric, or even to build up some positive pressure due to the momentum of the incoming stream. This sequence ensures that the cylinder is completely filled with fuel gas before compression begins, and the engine is enabled to "inhale a full breath", which is just as important to an engine as it is to a human body.

IGNITION FIRING POINT.

The development of full engine power is more dependent on accurate timing of ignition than on any other single factor. The valve phases are all controlled by the cams on a single camshaft, so that an error in valve timing will influence the power output of all cylinders equally. Moreover, the opening and closing points are fixed in relation to crank position, and do not vary with speed or load.

The instant of ignition, on the other hand, must be varied in accordance with speed and load, this being taken care of by the auto-advance mechanism of the distributor, which we discussed in the preceding lesson.

The basic timing point, determined by the setting of the contact breaker relative to piston and crank position, influences the whole range of automatic advance. This point is that at which the spark occurs, either at idling speed, when only vacuum controlled advance is applied, or at a stated crankshaft R.P.M. giving total auto-advance.

Fig.7 illustrates the firing point set 5 deg. in advance of top centre. When the spark ignites the compressed volume of gas, the conflagration must spread through the whole volume before the full force of the pressure wave is built up, and this means that there is a measurable time interval between instant of ignition and pressure peak. This interval will change with compression pressure, quality of fuel, mixture, temperature, and throttle opening. The time the crank takes to move through the 5 deg. is clearly a factor of speed. The piston can accept the full thrust when it has passed top centre, the best position being a few degrees past top.

At any given speed the pressure build-up interval must match the advance angle. Any deviation will cause loss of power. The effect is as follows:-

Too Far Retarded.

Late timing - advance angle too short - will allow the piston to move some way down its working stroke before full pressure is achieved, and this part of the stroke is wasted. The gas is still burning and under pressure when the exhaust valve opens. The power thrust is curtailed, exhaust outlet is hot and noisy, and the exhaust valve and seat become overheated by the passage of flame instead of burnt residue.

Too Far Advanced.

Early timing - advance angle too long - subjects the piston to the full pressure thrust before it has reached top centre, while still moving up.

The thrust tends to oppose and arrest motion, thus slowing down rather than speeding up rotation of the crank. A heavy load is imposed on bearings, and by the time the piston has reached a favourable position, much of the power has been uselessly expended and wasted.

Earlier timing can be used with advantage at higher speeds, as the piston will reach its best position when the pressure peak is attained, and full power can be developed. In Fig.8 the pressure build-up angle (a) extends from the instant of ignition, shown by a star, to the peak pressure position at W. The shaded area represents wasted power which results when the piston is anywhere in this sector at the instant of maximum pressure. Fig.9 shows the effect of retarded ignition, where a late start delays the build-up W beyond the best piston position at P. The shaded area again shows power wasted through lost motion on the power stroke, supplemented as we have already explained, by heat loss in the exhaust line.

Any one or more of these factors, together with others such as ignition efficiency, carburettion, and general mechanical condition, will affect the power performance. For purposes of diagnosis we need some common denominator which will be responsive to all these causes. We find the answer in the measurement of induction vacuum, which accurately reflects all the conditions bearing on performance and efficiency.

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LESSON 2

VACUUM AND COMPRESSION

The Principle and Practice of Testing Engine Vacuum and Compression

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

VACUUM AND COMPRESSION

THE IMPORTANCE OF VACUUM IN DETERMINING ENGINE CONDITION.

A piston in an engine cylinder does not suck air into the cylinder when it moves down on the intake stroke. The higher atmospheric pressure forces air into the cylinder through the carburettor and intake manifold. This atmospheric pressure amounts to 14.7 lbs. per sq. inch at sea level. At higher altitudes the pressure is lower.

When the piston moves down on the intake stroke as shown in Figure 10, a partial vacuum is created in the cylinder area above the piston. If no air can leak into the cylinder a vacuum will be created which can be measured by using a suitable Vacuum Gauge. If, however, there is a small air leak into the cylinder, atmospheric pressure will force its way in and the vacuum will decrease. This will take place slowly because of the time needed for the pressure to build up in the cylinder.

An engine, in addition to being a prime mover, is also a vacuum pump. It creates a vacuum with every intake stroke in the area between the carburettor throttle valve and the head of the piston on the intake stroke. If the engine is normal with good valves, piston rings and gaskets, the only leakage will be around the throttle opening and the wider this opening the lower the vacuum.

Figure 12 (Lesson 1) shows the application of a vacuum gauge for measuring average engine vacuum. The inlet valves "IV" open into a common manifold "M". Mixture enters at "C" through the throttle valve "T". A Vacuum Gauge with a movement "V" gives a reading in proportion to the vacuum created in the manifold.

With the engine running steadily at idling speed the vacuum gauge will register the average vacuum and will reliably indicate the general efficiency of the engine.

INCHES OF MERCURY.

Before studying vacuum indications in detail it is convenient to define the terms in which vacuum is measured. As already stated, air pressure at sea level is approximately 14.7 lbs. per sq. inch. A vacuum exists at any pressure lower than 14.7 lbs. per sq. inch down to zero pressure which is absolute vacuum.

The standard of measurement for vacuum is expressed in terms of the height in inches (or centimetres) of a column of mercury supported by air pressure.

Fig.13 shows an open ended glass tube "T" supported vertically with the upper end open to air pressure at "A" and the lower end immersed below the surface of a pool of mercury in a container "C". The level of mercury within the tube at "L1" will be the same as the surface of the pool at "L2" since the pressure is equal on both surfaces.

In Fig.14 a rubber hose is connected to the top of the glass tube and to the pump barrel "PB" within which is a piston "P".

When the pump handle is pulled up and the piston raised a partial vacuum is created in the lower barrel and hose and also in the space inside the tube "T". Air pressure "AP" on the pool surface now forces mercury up the tube. At any given degree of vacuum the height "V" of the column above the pool surface is always exactly proportional, so the vacuum concerned is described as equal to that number of inches of mercury at which the column stands.

A mercury column would be inconvenient to use for engine diagnosis and an alternative type of instrument is used as shown in Fig.15. The principle of the instrument is basically the same as a pressure gauge, except that it works in the opposite way. In the case of a pressure gauge, air is forced into a tube in the instrument which causes the tube to expand and operate a connecting link and gear which moves a pointer across a scale calibrated to read the pressure in lbs. per sq. inch. In the case of the vacuum gauge, the air is withdrawn from the tube and causes it to contract, similarly operating the connecting link and gear and causing the pointer to move across the scale which is calibrated in inches of mercury or - to use the normal symbol - "hg"

FACTORS AFFECTING ENGINE VACUUM.

Any faulty condition in the engine which causes a change in cylinder vacuum will be reflected by the reading of the vacuum gauge.

If the engine has a leaky manifold gasket there will be a slight air leak into the cylinder which will result in a small but noticeable loss of vacuum.

If, however, one of the valves were stuck and remained open there would be a much greater entry of air and a greater fall in vacuum. Also, compression would force gas back into the manifold and further reduce vacuum or increase pressure.

If the intake and exhaust valves operate satisfactorily and remain gas-tight when closed, but the piston rings do not form a proper seal to the cylinder wall, air will leak by the piston rings, vacuum will be lost and this loss will immediately be reflected in the vacuum gauge reading.

When the piston is moving downwards on its intake stroke, and a partial vacuum is created, the speed with which air can get into the cylinder past the throttle depends on the throttle opening and the speed of the engine. The vacuum gauge is, therefore, sensitive to speed and intake rate. Any adjustment such as ignition timing or carburettor idle mixture that increases the engine speed with a fixed throttle opening will also increase the vacuum.

Any condition which causes the speed of one cycle of the engine to vary with another, creates a difference in the intake vacuum which will be registered in the vacuum gauge either by an intermittent fall in the vacuum reading or a slow backward and forward movement of the pointer.

Some of the factors which cause this to happen are -

(1) A failure of the valves to open and close at the correct time.

(2) A failure of the valves to make proper contact on the valve seats.

(3) Faulty ignition which changes the timing of the spark in a cylinder.

(4) Incorrect carburettor adjustment resulting in improper combustion, or uneven engine speed.

(5) Internal defects in the carburettor.

Vacuum readings are particularly sensitive to ignition timing. If the ignition is advanced, and there is an increase in engine r.p.m. with no change in the throttle opening, a higher vacuum reading indicates that the changed ignition timing has improved engine performance. If, however, the timing is too far advanced it will result in a spark occurring before the correct firing point. This will result in a reverse pressure on the piston head which will slow down the engine speed and cause the vacuum reading to drop.

The vacuum reading is also sensitive to carburettor idle speed adjustment. If the mixture is made too rich, the speed, and consequently the vacuum, will fall. If the mixture is made too lean the engine will be starved and there will also be a fall in engine speed and a proportionate loss in vacuum. Both speed and vacuum indications become irregular and unstable.

ANALYSING ENGINE CONDITION BY VACUUM MEASUREMENTS.

Having carefully studied the foregoing, you should now be quite clear about how vacuum is created and the basis of its measurements so that we can now proceed to examine the indications given by the vacuum gauge and interpret the readings as pointers to various conditions in the engine.

VACUUM INDICATIONS OF A HEALTHY ENGINE.

An engine in good condition will give a vacuum reading as shown in Fig.16, averaging 18 to 22 inches at manufacturer's specified idle speed. These readings apply to tests at levels approximating to sea level. When tests are made at high altitudes the vacuum reading will be lower. For each 1,000 ft. above sea level the vacuum gauge will read approximately $\frac{3}{4}$ inch lower. If, therefore, an engine in good condition registers 21 inches of vacuum at sea level, the same engine tested at 2,000 ft. above sea level will read 19.5 inches of vacuum.

FIG. 14.

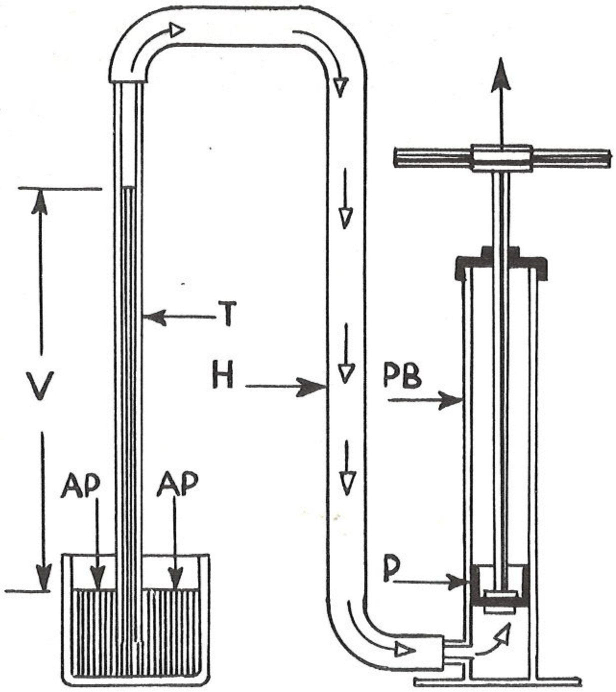

T
V
H
PB
AP
AP
P

FIG. 15.

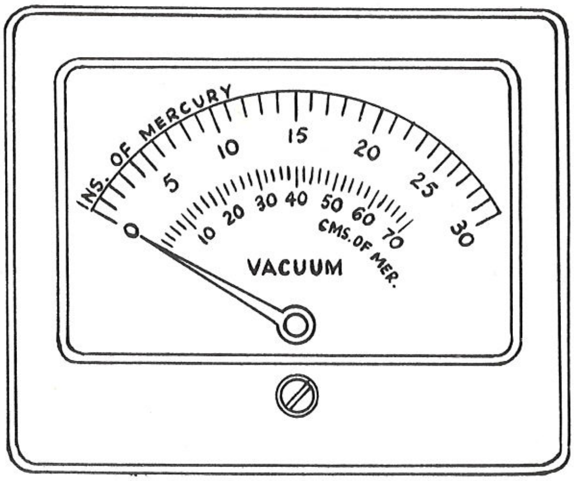

INS. OF MERCURY
0
5
10
15
20
25
30
10
20
30
40
50
60
70
CMS. OF MER.
VACUUM

FIG. 16.

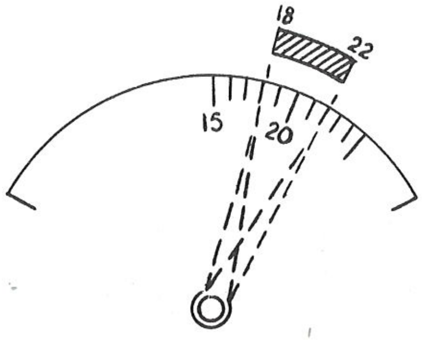


FIG. 17.

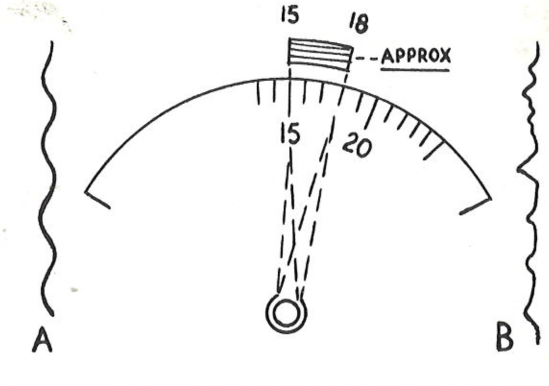

15
18
APPROX
15
20
A
B

FIG. 18.

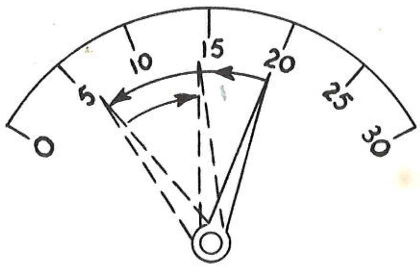
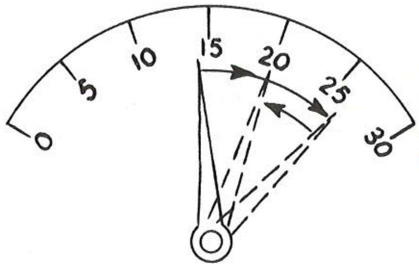

0
5
10
15
20
25
30

FIG. 19.


0
5
10
15
20
25
30

VACUUM INDICATIONS WITH DEFECTIVE ENGINES.

From a practical point of view, vacuum gauge indications fall generally into two kinds:-

(1) Vacuum readings which are low but steady.

(2) Vacuum readings which are irregular.

Low But Steady Readings.

The main engine defects which cause low and steady readings are as follows:-

(1) Very low readings from 3 to 10 inches.

(a) Leaky intake manifold gaskets.
(b) Leak in heat riser tube.

(2) Low steady readings of 10 to 15 inches.

(a) Late ignition timing.
(b) Defective piston rings.
(c) Worn cylinder walls.
(d) Leaky valve guides.
(e) Leaky manifold gaskets.
(f) Leak in heat riser tube.

(3) Normal reading at idling speed, decreasing as engine speed is increased.

(a) This indicates a choked exhaust. To check for this trouble it may be necessary to run the engine at a high speed for several minutes.

Unsteady - Regular Drop in Vacuum Reading.

The main causes of an unsteady reading and a regular drop in vacuum are as follows:-

A synchronous flicker or drop in the reading at idling speed shows that in at least one cylinder power is being wasted by a plug misfire, faulty valves, leaking gasket or piston rings. The indication may appear at all speeds, at idling, or on acceleration and will be more prominent on four cylinder than eight cylinder engines. The cylinder can be identified in many instances by shorting out the plugs one at a time, watching for the cylinder which on shorting out, has the least influence on the reading.

Burned or leaky valves are indicated by a periodic drop in vacuum which may vary from 1 inch to 6 inches. The drop will be regular since the leak occurs each time the faulty valve attempts to close. If more than one valve is leaking the action will be more frequent and the frequency will depend upon the number of valves affected.

Sticking Valves. A sticking valve is indicated by the vacuum gauge needle dropping

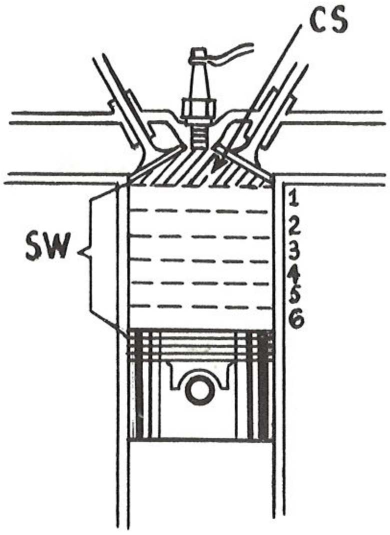


FIG 20

CS
SW
1
2
3
4
5
6

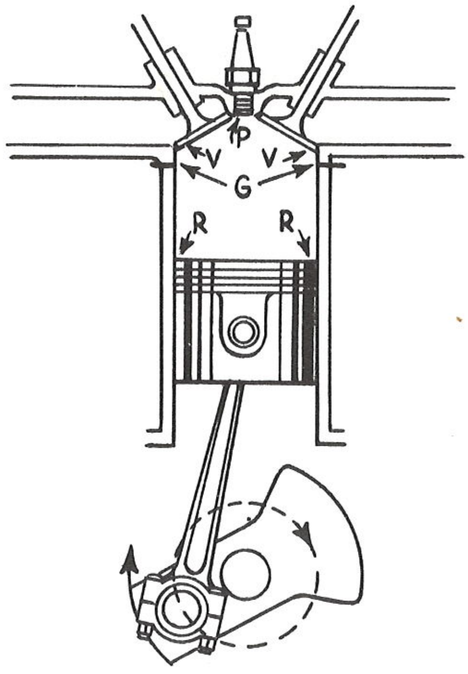


FIG.21.

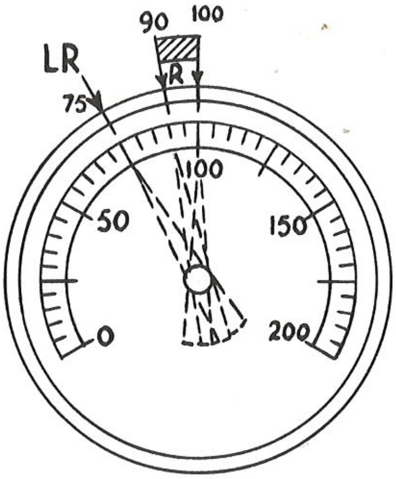


FIG.22.

90
100
LR
R
75
100
50
150
0
200

intermittently, usually about 2 inches to 4 inches as in Fig.17. The indication differs from a burned valve because it is not so regular. This trouble can be verified by injecting a small amount of penetrating oil into the intake manifold. If this steadies and raises the reading it proves the need of valve reconditioning.

Weak or broken valve springs are shown by a vacuum reading which fluctuates wildly as shown in Fig.18, the speed of the fluctuations increasing with engine speed. To make this test the engine should be run at the highest speed practical.

Loose valve guides give indications generally similar to weak valve springs but the fluctuations will steady out as the speed is increased, due to the valve tending to find its natural centre.

If, when making the test, there are wide variations of the vacuum gauge needle when the engine is racing, the indication is weak or broken valve springs or a sticking valve. When the throttle is quickly opened and closed, the pointer should drop to about 2 inches, on acceleration and quickly rise to about 25 inches on deceleration, and then settle to a normal reading as idling speed is restored. If the pointer drops to zero and does not rebound as much as 25 inches, and then settles to a reading lower than the normal idling vacuum, the implication is poor rings or deficient lubricating oil.

If it is noticed that there is a regular drop of the vacuum gauge pointer of from 2 to 6 inches, the indications are that a valve is being held open or is burned or there is a spark plug miss or a leak in the cylinder head gasket.

If there is an irregular drop of the pointer of from 2 to 6 inches, the indications are gummy valve stems or guides, an intermittent spark plug miss or wrong carburettor adjustment.

A slow hunting of the pointer from about 10 to 15 inches indicates that the carburettor may be out of adjustment or the spark plug gaps set too close ... late valve timing can also cause this reading. A slow oscillation of the pointer from normal vacuum to about 14 inches as Fig.19 indicates that the carburettor is out of adjustment or the plug gaps set too close.

It will be clear from the foregoing that no hard and fast rules can be established for the exact indications of various vacuum gauge readings. The mechanic with experience will soon learn to judge with accuracy the various indications of the vacuum gauge and full proficiency in its use can only be obtained by regular use and by keeping notes of the actual causes found which are initially indicated by vacuum gauge readings other than normal.

ADJUSTING IGNITION TIMING.

If the engine runs evenly and shows a steady high vacuum, when warm and the throttle is set to the lowest steady tick-over, there is evidence that the general condition of the engine is good and probably hard to improve.

Since it is impossible to specify the actual maximum vacuum which any engine should give, an adjustment of ignition timing should always be made to see to what extent this will improve existing performance.

To adjust ignition timing, slacken the clamping screw and very gradually move the distributor round against the direction of rotation until the maximum vacuum reading is attained. Then retard ignition until the vacuum reading falls by approximately ½ inch for good grade petrol or ¾ to 1 inch for lower grade petrols. The adjustment should be made with an engine speed of approximately 1,200 to 1,500 to bring in full automatic advance.

ADJUSTING CARBURETTOR SLOW RUNNING MIXTURE.

The vacuum gauge gives a reliable indication of the correctness or otherwise of the slow running mixture.

An over rich mixture will produce a rhythmic wavering motion of the pointer, usually synchronous with every second beat of the engine and illustrated in Fig.17A. Over-lean mixture is characterised by intermittent misfire which the gauge shows as an irregular flicker of the pointer illustrated in Fig.17B. When the idling mixture adjustment screw of the carburettor is turned in the right direction, the gauge pointer will be seen to steady down at a higher reading and the engine will run more evenly. If it is turned in the wrong direction this will be instantly disclosed by the erratic or uneven vacuum indication becoming more prominent.

The mixture may be incorrect, not sufficiently to cause obviously uneven running, but still indicated by an irregular low reading of the gauge. In either event the adjustment correction should be made to attain the highest steady reading, beyond which any further alteration causes the vacuum to fall or to become unsteady again.

ENGINE COMPRESSION.

In modern practice engine compression is stated in terms of ratio rather than in lbs. per sq. inch. Fig.20 illustrates how compression is assessed.

The shaded area in the cylinder head is the combustion space or chamber being the space between the piston crown and the cylinder head in top centre position. The barrel space "SW" is the "swept volume" traversed by the piston on each stroke. When the volume of this space is say, six times that of the combustion space "CS" the compression ratio is 6 : 1, meaning that the total swept volume of six is now compressed into 1.

It may be thought that if the compression ratio is known we could find what pressure should be reached by multiplying atmospheric pressure by the ratio. On this assumption a 6 : 1 ratio at sea level with an atmospheric pressure of 14.7 lbs. per sq. inch should produce nearly 90 lbs per sq. inch compression. This is, however, an erroneous conclusion because many factors enter into the question such as temperature, humidity, speed of compression, fuel density etc., and consequently we cannot rely on this result.

The normal compression level can be changed from standard by the use of a thicker or thinner cylinder head gasket or some other modification.

When the engine is mechanically standard to specifications, however, compression tests are made for the purpose of comparing leakage loss in unit cylinders and we are therefore mainly concerned with variation rather than actual readings.

PRESSURE LEAKAGE.

From the instant the inlet valve closes on the up stroke of the piston on compression the gas is trapped in the cylinder and its pressure rises progressively above atmospheric pressure as the volume is reduced.

In the same way as outer air pressure will force its way into a low pressure area, so will high pressure tend to drive gas out of the cylinder into the outer air space through any crevice or weak joint it may find. Fig.21 shows where these leaks may occur - past the valve heads at "V", the piston and rings at "R", the plug gasket at "P" and the cylinder head gasket at "G". Any crack or pin hole in the piston crown or cylinder wall would also allow gas to escape.

Compression leakage is one thing, but we have to remember that from the instant of ignition, the combustion pressure wave rises sharply up to four times the maximum pressure reached. Leakage will, therefore, be accentuated during the firing or power stroke, and that is where loss of compression means loss of power and performance.

THE COMPRESSION GAUGE.

The instrument used for measuring and comparing compression is a Bourden type Compression Gauge similar in form to the Vacuum Gauge but with a pointer which moves over the dial in response to the rise of pressure above the atmosphere. The scale is calibrated in lbs. per sq. inch up to 200 in 5 lb. steps. The Crypton Compression Gauge is a specially designed instrument with a convenient pistol-grip handle and an adjustable tubular stem terminating in a conical rubber plug, containing a non-return valve.

METHOD OF COMPRESSION TESTING.

The essential point to remember about compression testing is that all cylinders must be tested under exactly the same conditions as far as this is possible. A basis of test is established on the first cylinder and the remaining cylinders are compared with the results on the first.

All plugs are removed and ignition switched off. Where the starter control is wired to the ignition circuit so that the starter cannot be operated unless ignition is "ON", the coil output must be directed to earth or the coil disabled. The simplest way of doing this is to connect a jumper lead to the distributor "CB" terminal and earth so that the primary circuit remains closed and no sparks occur.

On some American systems using an armoured cable with locking switch, the "CB" terminal is not accessible and in this case the coil HT lead must be disconnected from the distributor and connected direct to earth.

The throttle must be held wide open while the compression test is made to ensure that each cylinder takes a full breath and its volume of intake is not choked by throttle restriction.

The compression tester is held firmly in the plug hole of the first cylinder and the starter is then operated, the gauge being carefully watched.

As the starter turns the engine, the compression gauge reading will increase in steps, until the pressure build-up in the gauge reaches a maximum. The maximum reading thus obtained is the full compression pressure reached in the cylinder.

This reading is carefully noted and a similar test then made on all other cylinders.

Equality of readings is established by carefully counting the number of cycles through which the engine is turned on the first cylinder tested and rotating the engine for the same number of turns for the other cylinders.

Some variation of compression is inevitable in an engine which has not been recently reconditioned and a maximum variation of 10 lbs. per sq. inch is allowable. The less the variation, the better the engine condition.

Fig.22 illustrates a typical reading where the maximum is 100 lbs. and the minimum 90 lbs. The lowest reading cylinder is just within the tolerance "R" and the engine condition could be graded as "Passable" although not exactly first class. When one cylinder shows a reading outside the limit as at "LR" then the compression loss is excessive and service is needed.

A simple test enables the source of leakage to be determined, i.e., whether past piston or rings. A small quantity of oil is injected around the top edge of the piston and the test repeated. If the test with the oil shows an improved reading, it indicates that the leakage is mainly past the rings. If there is no improvement on the oil test the leakage is past valves, gaskets, etc.

It should be noted that in the case of a cylinder having a bad score down the barrel, the oil seal will fail to close off the leak and no improvement in reading will result.

The behaviour of the Compression Gauge during the pressure build-up will indicate the general condition. The first compression phase should produce a high reading and a maximum should be reached in a very few cycles. A low initial reading with a slow build-up over several cycles points to a high rate of compression leakage - this should be remembered while making the test. A cylinder showing this slow build-up will almost certainly produce a lower maximum pressure than the others.

A point to be noted when making compression tests is the relative cranking speed for each cylinder tested. If the battery is nearly discharged - particularly when carrying out tests of an eight-cylinder engine - the cranking speed for testing the last cylinder will be lower than for the first and the pressure reached after a given number of cycles may be lower.

Tests should, therefore, always be made on a fully charged battery which is, incidentally, one reason why it is important to make all tests in a full diagnosis in their proper order as described in the last lesson of this Course.

All students will realise from a study of the foregoing information that vacuum and compression tests are very important in ascertaining the mechanical efficiency of the engine.

The study of this lesson will have made clear the underlying reasons for vacuum and pressure changes as well as the testing procedure. Make sure that you thoroughly understand the principles and the practice involved before proceeding with the study of the next lesson.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 3

AUTOMOBILE BATTERIES

What to Know About Battery Construction, Operation, Testing and Charging.

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

AUTOMOBILE BATTERIES

Many millions of pounds are paid every year for the charging, servicing and replacement of batteries and for many other operations and supplies such as voltage regulators, generators, starters, battery cables and fan belts, the need of which is evidenced by the condition of the battery.

The battery is the heart of the automobile electrical system and yet is one of the most abused and neglected components on the vehicle. So long as the battery supplies sufficient energy for starting the average car owner never even thinks about it ... never worries about its condition ... whether it is losing its charge ... whether defects are developing which will ultimately result in inconvenient troubles. The owner cannot be blamed for this ... he hasn't the means of testing his battery ... special equipment is needed for this which he hasn't got. He depends upon his garage for the adequate servicing of his battery and unfortunately is often disappointed because comparatively few service stations give the battery the attention it needs. In some cases the Battery Department is even considered a nuisance, a remarkable state of affairs when we consider the fact that millions of pounds are spent every year for battery service and replacements with an even greater expenditure for other service operations to which the battery is a leader.

An important essential in battery business is the man who does the work. Without capable and intelligent mechanics who understand the battery and appreciate its importance complete success in battery service is not possible. It is because of this that we have devoted one Lesson of the Crypton Course to a detailed practical explanation of the battery, its position in the electrical system, what it does, what happens if the battery is defective, what troubles are likely to occur, and how these troubles can easily and quickly be located and corrected.

So important is the battery in every vehicle electrical system that until its condition has been determined no efficient diagnosis of electrical system or engine condition can be satisfactorily carried out. If the battery is faulty or discharged it must be recharged or replaced before a diagnosis can disclose any additional services or corrections which may be necessary.

It is not necessary for the service man to be an absolute battery expert but, he must understand the normal operating functions, the proper tests needed to determine battery condition and the correct conclusions to be drawn from the results of these tests. Any service man who studies this lesson carefully will become proficient in diagnosing battery condition and be able confidently to report results and prescribe such treatment as is necessary to restore good battery performance.

BATTERY CONSTRUCTION.

You all know what a battery looks like. It comprises a moulded case divided into three compartments for a 6-volt battery or six compartments for a 12-volt battery, each compartment closed by a sealed in top or lid in which is

FIG 1

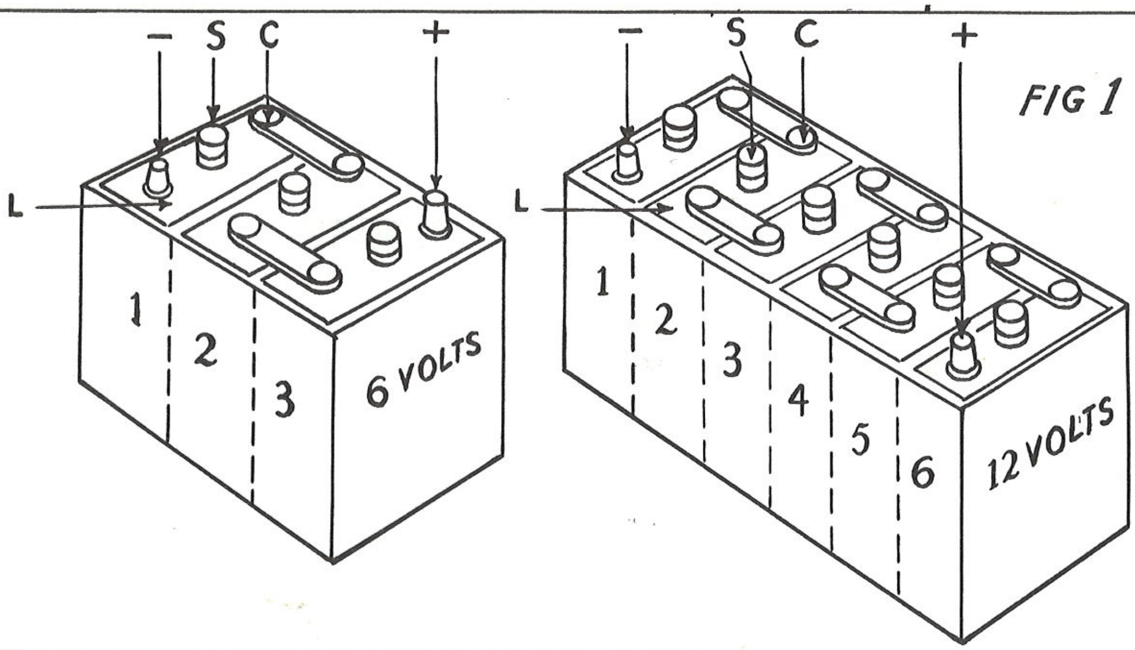

−
S
C
+
L
1
2
3
6 VOLTS
−
S
C
+
L
1
2
3
4
5
6
12 VOLTS

FIG 2

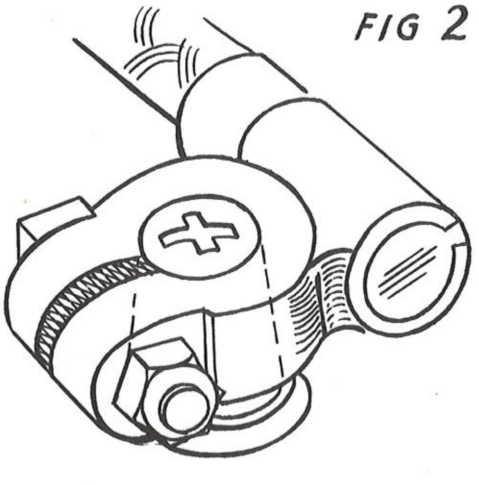


FIG 3

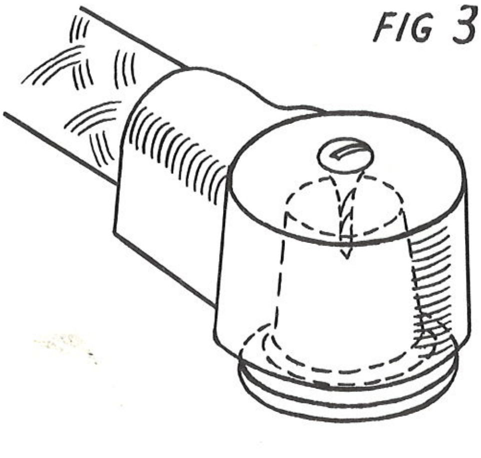


FIG 4

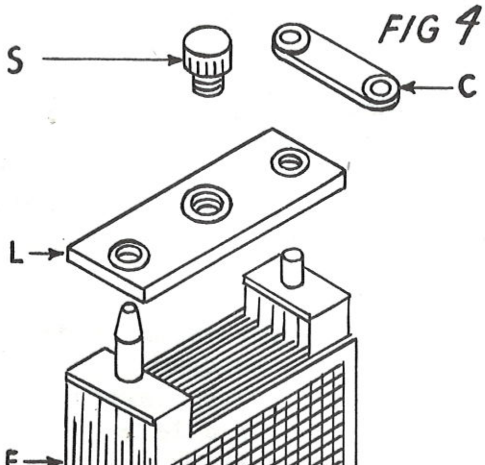
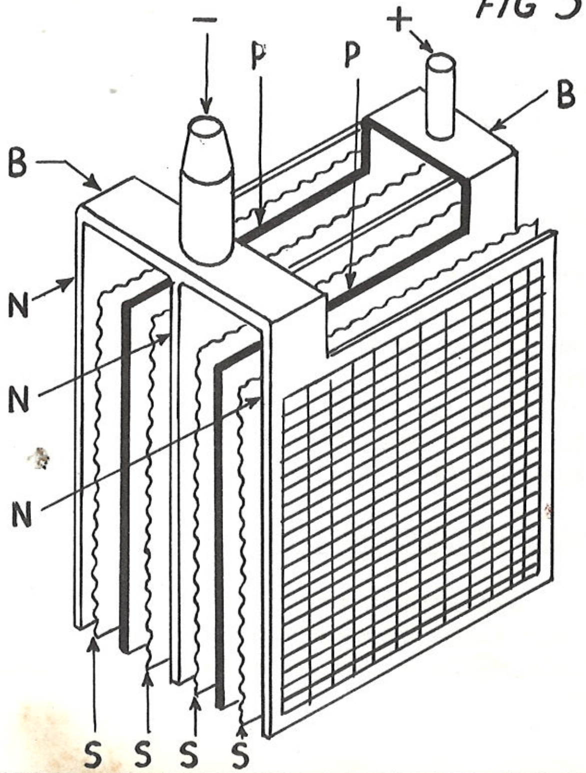


FIG 5


−
P
P
+
B
B
N
N
N
S
S
S
S

a screwed aperture with removable plug or stopper. Each compartment is called a "cell" and has two lead posts or terminals, one slightly larger than the other and both tapered. The larger terminal is the positive post with a plus sign and the smaller terminal the negative post with a minus sign. The heavy battery cables are connected to the terminal posts by lead plated brass clamps with tapered bores, secured by a bolt and nut. This is the standard S.M.M.T. terminal clamp commonly used for many years. Many modern British cars are, however, now equipped with a new type having an inverted lead cup on the cable end, secured on the post by a screw. One post of each cell is connected to one post of its neighbouring cell by a cast lead bar called "inter-cell connector". In some cases these links are not always visible, being embedded in the sealing compound which joins the lid of the cells to the compartment. The remaining posts of the end cells of the battery are the main terminals.

Each cell has a nominal voltage of two volts between its terminals and since all cells are connected in series, the total voltage of a three-cell battery is six volts and a six-cell battery twelve volts. Fig.2 illustrates a typical S.M.M. & T. type terminal and Fig.3 shows the Lucas type inverted cup cable connector.

The battery case is usually provided with lugs with long screw bolts or other fixing to secure the battery in the box or cradle on the vehicle holding it firmly against vibration.

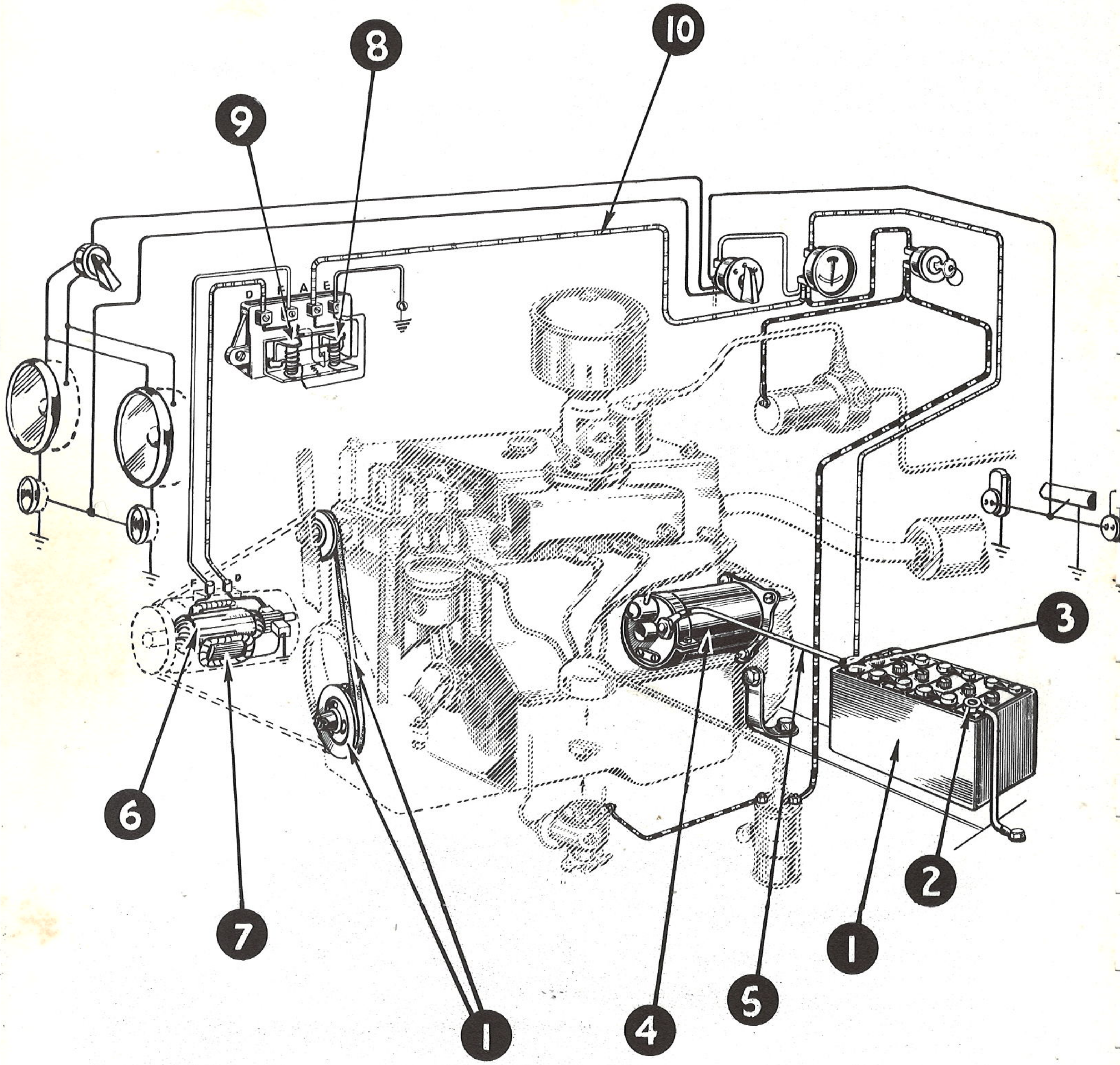
CELL CONSTRUCTION.

Fig.4 shows an "exploded" view of a single battery cell. To open up the cell the stopper "S" is removed, the link "C" taken off and the lid "L" lifted. The cell element "E" can then be lifted out of the container.

Fig.5 shows the construction of the cell element which comprises two sets of thin rectangular plates with extended lugs at the top. One set of plates is the positive group marked "P" and the other set the negative group marked "N". The plates are interleaved like the fingers of clasped hands but do not make actual contact, being spaced apart by sheets of insulating material or separators. The positive plates are chocolate brown in colour and the negative plates of light grey colour.

Both positive and negative plates consist of a lead grid in which a hard chemical compound called "the paste" is compressed. Fig.5 shows a cell with a total of 5 plates, 3 negative and 2 positive. Standard automobile batteries have a greater number of plates, for example, nine plate, eleven plate or thirteen plate. There is always one more negative plate than positive, so that an eleven plate cell consists of five positive and six negative plates.

When the cell is in position in its compartment the plates and separators are immersed in a solution of sulphuric acid and distilled water known as the "electrolyte". The electrolyte must be approximately $\frac{1}{4}$ inch above the surface of the plates.


D
F
A
E
F
D

WHAT THE BATTERY DOES.

The battery plays a vital part in the operation of the vehicle electrical system. Its position is shown in the accompanying diagram which shows the basic electrical system fitted in every vehicle.

All the electrical energy required for starting, lighting, ignition and the operation of the many electrical accessories fitted to the modern car comes originally from the generator. The battery serves as a reservoir or storage tank from which electrical power can be drawn when the generator is not running or when its output is not equal to the total electrical demand. The battery then makes up the difference between the supply and demand.

When the engine is started a heavy current is drawn from the battery to operate the starter and crank the engine and also to supply the voltage needed for ignition. With the engine idling or running at very low speed the battery continues to provide all the electrical energy required. When the engine exceeds a certain speed called the "cutting in" speed the circuit between the generator and the battery is completed and the generator will then send a current into the battery and "charge it". Whilst doing this the generator also supplies the energy needed for ignition, lighting, etc. The flow of current from the generator into the battery causes a chemical change to take place which has the effect of "storing electricity". When sufficient electrical energy has been put into the battery to complete this chemical change, the battery is described as fully charged - equivalent to a full tank. All the electrical energy required during the period when the generator is not charging the battery is "drawn off" from the battery and this causes a reverse chemical change to take place to that experienced during charging. When the amount of electrical energy taken from the battery is such as to complete the reverse chemical process, the battery is said to be discharged. The capacity of a battery determines how much energy it will absorb on one charge and re-deliver during discharge.

CHEMICAL ACTION DURING CHARGING.

With a battery in a discharged condition the paste on the positive and negative plates is called "lead sulphate" and the electrolyte consists mainly of pure water with a small amount of sulphuric acid. The voltage of each cell with no load applied to the battery will be approximately 1.8 volts and if a normal load is applied the cell voltage will drop even lower. Fig.6 shows a simple cell with three Negative plates "N", two Positive plates "P" and the Separators. The electrolyte level is indicated at "EL" and the cell plates rest on ridges across the bottom of the cell compartment "R". A space is left "SF" at the bottom of the cell compartment for the collection of sediment which is dislodged from the plates during the normal operation of the cell.

If the cell is connected to a source of direct current supply such as the car generator or an outside battery charger current flows through the cell in the direction shown by the arrows. The current enters at the positive terminal and leaves by the negative terminal, passing from the positive plates, through the electrolyte and separators to the negative plates.

The passage of electrical energy through the electrolyte starts a process

FIG 6

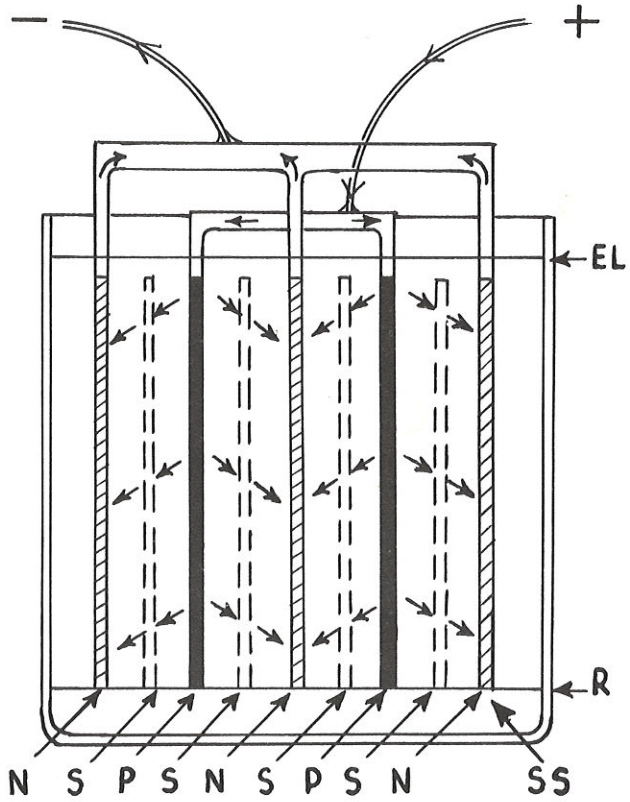
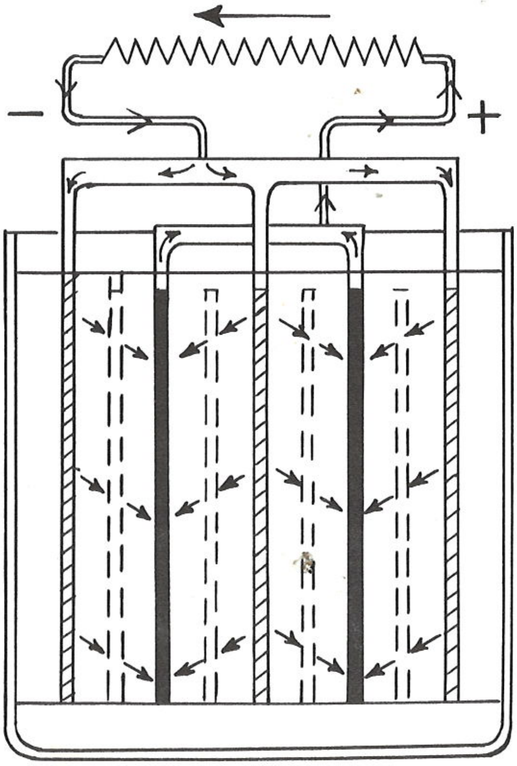

−
+
EL
R
N S P S N S P S N
SS

FIG 7



known as "electrolysis". Oxygen particles from the water (composed of oxygen and hydrogen) are attracted to the positive plates where they form a compound known as "lead peroxide". The sulphate in the positive plates is displaced and returns to the electrolyte. The sulphate of the negative plates is also returned to the electrolyte, leaving the material on the negative plates to become spongy metallic lead. This process continues as long as the charging current flows through the cell until all the active sulphate has been dislodged from the plate surfaces and returned to the electrolyte. When the change of material has been completed the cell is said to be fully charged and no further purpose is served by continuing the flow of charging current.

As the cell is charged more and more sulphate or acid is returned to the electrolyte which becomes "stronger". The strength of the electrolyte is called "Specific Gravity" the meaning of which we shall describe later. As the cell is charged the temperature of the plates and the electrolyte increases and the hydrogen which is released from the electrolyte escapes in the form of gas bubbles which can be seen rising to the surface of the electrolyte when the cell is nearing its fully charged condition.

If a voltmeter is connected to a cell after it has been fully charged the voltage will be approximately 2.1 volts. A load can now be applied to the cell and will cause only a very small drop in this voltage. We now have a reserve of energy on which we can draw and we can continue to take a current from the cell during which the following process takes place.

CHEMICAL ACTION DURING DISCHARGE.

In Fig.7 we see the cell previously described with a load connected across the positive and negative terminal. Current now flows from the positive terminal of the cell, through the load and returns to the cell via the negative terminal. The flow of current inside the battery is indicated by the short arrows and is in the reverse direction to the current flow during charge.

The effect of this reverse current flow is to reverse the chemical change which took place during charge. Acid is re-absorbed from the electrolyte in forming sulphate in the positive and negative plates. The lead peroxide in the positive plates is gradually changed to lead sulphate and the spongy lead in the negative plates also changes to lead sulphate. Since acid is taken from the electrolyte and absorbed in the plates, the electrolyte becomes "weaker" and its specific gravity falls.

When a sufficient current has been taken from the cell to complete the reverse chemical process, the cell is said to be discharged with a weak acid solution and a low on-load voltage.

It is very important that the cell is not left in this discharged condition and is re-charged immediately. If the cell is left fully discharged the sulphate in the plates will harden and form crystals which will not readily dissolve and re-enter the electrolyte during subsequent charging but will remain to choke the active material and reduce the capacity of the battery.

BATTERY CAPACITY.

The capacity of a battery indicates how much energy it will hold and how much power it will deliver as a useful discharge. The actual capacity of the battery is determined by the total area of the plates, which means that for a standard size and form of plates the number of plates per cell decides the capacity of the battery.

Capacity is measured in "ampere-hours" which is the product of current flow and time. A battery rated as having a capacity of 60 ampere-hours at the 20-hour rate means that it will be discharged when a current of 3 amperes is taken from the battery for a period of 20 hours. This does not mean that the battery will not give a greater current than 3 amperes; it will actually give a much higher current up to 300 amperes for starting the engine, but - if the current exceeds 3 amperes the capacity of the battery is proportionately reduced. In the case, for example, of a 60 ampere-hour battery at the 20-hour rate, a steady current of 3 amperes can be taken for 20 hours before the cell is discharged. If a steady current of 10 amperes were taken from the same cell this current might be taken for only 5 hours which means that the effective capacity of the battery at the higher current would be only 50 ampere-hours.

All discharge rates over the normal capacity current involve a loss of capacity. The higher the current draw the lower the capacity of the battery. A large capacity battery will give a greater current with a lower fall in voltage than a battery of lower capacity. It will also require a longer period of charging at a given current or charging for the same period at a higher current than in the case of a battery of lower capacity.

THE MEANING OF SPECIFIC GRAVITY.

As we have previously seen, when a cell is discharged acid leaves the electrolyte and enters the plates, causing the electrolyte to become "weaker". The reverse process takes place when the battery is charged, the acid leaving the plates and re-entering the electrolyte, causing it to become "stronger".

This characteristic means that we can use the strength of the electrolyte or its "specific gravity" to determine the extent of charge of a battery. We can measure the "strength" of the electrolyte by measuring the specific gravity by which we mean the weight of the electrolyte as compared with pure water. A solution of water and sulphuric acid is heavier than pure water and we can measure the relative weight by using a hydrometer. If the amount of sulphuric acid in the electrolyte is such as to make the electrolyte 1.28 times as heavy as a similar volume of water, the hydrometer will give a reading of 1.280 and we call this reading the "specific gravity".

In most starter batteries the cells are initially filled with electrolyte having a specific gravity of 1.350. This soaks into the plates and separators and gives a final electrolyte specific gravity of approximately 1.280 in a fully charged cell. As the cell is discharged the acid enters the plates to form sulphate and the specific gravity weakens as follows:-

Specific gravity 1.280 indicates that cell is 100% charged.
" " 1.250 " " " " approx. 75% charged.
" " 1.220 " " " " " 50% "
" " 1.190 " " " " " 25% "
" " 1.160 " " " has very little useful electrical energy left.
" " 1.130 " " " is completely discharged.

TESTING BATTERY STARTING CAPACITY.

To test battery starting capacity it is essential to apply a load equivalent to the normal starter load. The starter itself can be used and the voltage of the complete battery or each cell measured whilst the starter is operating. An alternative method is the use of a Heavy Discharge Cell Tester which incorporates a resistance which when applied to the battery imposes a load equivalent to the normal starter load, the voltmeter of the Heavy Discharge Cell Tester measuring the cell voltage whilst this load current is applied.

A load test applied for a period of five to six seconds applied to a healthy fully charged cell will show a small voltage decline as is evidenced in the starting periods "A" and "B" in Fig.10. If, however, the voltage falls away rapidly during the five to six seconds application of the load as is evidenced in the starting periods "D" and "E" then it is obvious that the battery has reached the end of its reserve of starting power and will certainly fail to operate the starter satisfactorily on a cold engine although it might just get a warm engine to start. If, therefore, the test shows a low or rapid fall of voltage it is a sure indication that battery starting capacity is inadequate for good starting service. Details of the application of heavy discharge testing are given later.

EFFECTS OF TEMPERATURE ON BATTERY PERFORMANCE.

The chemical changes which take place in a battery are retarded by cold weather and accelerated in hot weather. This means that battery performance is appreciably affected by temperature.

To illustrate this we will take the power potential of a healthy fully charged battery as 100% at a temperature of 80 degrees F. If this battery is operated at a temperature of 32 degrees F. its power potential is only 65%. At a temperature of 0 degrees zero the power potential is only 40%.

At the same time that the battery loses a great deal of its power potential the engine requires an increased amount of power because of the high oil drag of a cold engine, weak ignition through voltage decline and other cold starting disabilities. At 32 degrees F. an engine requires 65% more power to start it, whereas the battery gives only 65% of its normal power. At a temperature of 0 degrees F. the engine requires 25% more power from a battery which will give only 40% of its normal power. These figures clearly show how vital it is to ensure that batteries are kept in a fully charged condition under cold weather conditions.

Conversely, a high temperature will help the battery to give a lively performance but unless a proper correction of the specific gravity is made this will shorten the effective battery life. A fully charged specific gravity of 1.280 at 60 to 80 degrees F. will ensure correct chemical action but at higher temperatures the corrosive property of the acid is greater and there is a risk of disintegrating the lead grids and the separators. For this reason battery manufacturers specify lower specific gravities in tropical countries. The fully charged specific gravity instead of 1.280 is only 1.250 and may be as low as 1.225 according to local temperature conditions. An important point to watch in operating batteries of low temperature is the freezing of the electrolyte. If the battery is discharged the electrolyte will consist mainly of water which means that the freezing point of the electrolyte is raised nearer to 32 degrees F. There is a much greater danger of freezing of batteries in a discharged condition with low electrolyte gravity than in the case of batteries which are fully charged with a higher acid content where the freezing point is much lower.

CAUSES OF POOR BATTERY PERFORMANCE.

The causes of unsatisfactory battery performance can be specified as follows:-

Faulty conditions within the battery disclosed by cells showing unequal states of charge, due to internal faults such as buckled plates, damaged separators, disintegrated active material sulphation or other defects which render the battery incapable of further useful service.

Faulty conditions in the electrical system resulting in excessive power drain on the battery or insufficient charging. When this is the case a normally healthy battery will show a low state of charge equally on all cells but will respond readily to charging from an independent source.

One of the most frequent causes of battery deficiency is age, due to the fact that constant charging and discharging will gradually lower the battery capacity until it becomes too low for continued good service. A contributory factor is the deterioration of the battery due to lack of maintenance and it must be admitted that this is one of the main causes of many battery troubles. Neglect of periodic topping up of the electrolyte allows the level to sink exposing the plate surface to the atmosphere, resulting in drying out, heating, hardening and crystallization. This reduces the effective area of the plates, lowers the battery capacity, imposes a greater strain on the battery and shortens its life.

The replacement of spilled electrolyte with water makes the electrolyte too weak which causes increased internal resistance and upsets the relationship between specific gravity and state of charge. In this case the hydrometer readings are false and will bear little reference to the true cell condition.

Replacing the spilled electrolyte with acid solution has the reverse effect and will cause the specific gravity to become too high, causing deterioration of the electrolyte and again producing false hydrometer readings.

Bad mounting of the battery will cause the case to wear, will distort fixing lugs and result in cracks and leakage.

Overcharging will result in excessive gassing of the electrolyte causing overspill, wet and leaky cell lids, buckled plates and the bursting of lids. Rapid corrosion of the cable connections and cables will follow, the lid bulging will break the sealing and surrounding metal will be attacked by acid evidenced by a coating of white powdery iron sulphide. All these points should be checked on inspection and the necessary corrective measures recommended. In many cases the defect mentioned above will justify the sale of a new battery. Other contributory causes of breakdown such as poor mounting or unsatisfactory charging must be corrected at the same time.

PRINCIPLE OF THE HYDROMETER.

The instrument used to measure specific gravity is the Hydrometer illustrated in Fig.8. It consists of a glass syringe "A" with a rubber tube "B", a bulb "C" and a hydrometer float "D" comprising a sealed glass tube with a lead weight "E" at the bottom and graduated scale "F".

To measure specific gravity the tube is inserted in the electrolyte in the cell, the bulb operating to draw electrolyte into the bulb when the hydrometer will float and the value of specific gravity will be read by the scale graduation read level with the surface of the electrolyte as shown at "G". After testing the sample of solution is returned to the same cell from which it was taken and the test repeated on each cell in turn.

It is necessary to correct the specific gravity reading for temperature by adding four points to each 10 degrees of temperature in excess of 80 degrees F. and subtracting 4 points for each 10 degrees by which temperature is below 80 degrees F. If, for example, the reading is taken at a temperature of 30 degrees F. and the hydrometer reads 1.220, this is 50 degrees F. below the normal figure and 20 points must be subtracted from the hydrometer reading giving a final corrected specific gravity of 1.200.

From a practical point of view there is little need to worry about temperature correction where the actual temperature is closely approximate to 80 degrees F. but in the case quoted the temperature correction is important. The initial test of 1.220 indicated that the cell was 50% charged whereas with the temperature correction made, giving a final figure of 1.200 it is seen that in actual fact the cell is little more than 25% charged and needs immediate recharging.

VARIATION OF CELL VOLTAGE.

Testing the specific gravity of a battery is under normal conditions a satisfactory commercial method of determining battery state of charge. It is, however, often a "messy" job and because of this many service men do not test battery state of charge as frequently as is desirable to give good service. In order to make specific gravity tests it is also necessary that the level of electrolyte should be correct. If the electrolyte level is low it is necessary to top up the cells with pure distilled water before a specific gravity test can be made. In this case it is necessary to allow the cell to stand for a recommended period of four hours before the test is made so that the distilled water can thoroughly mix with the remaining electrolyte in the cells.

Because of these difficulties and to help the service shop to carry out battery state of charge testing with greater speed and convenience, an alternative method of open circuit voltage testing has recently been developed. This method of testing is based upon the fact that in exactly the same way that there is a variation in specific gravity between a charged and discharged battery, so there is a variation in the open circuit voltage of the battery cells. This open circuit voltage means the voltage of the cell taken when no current is flowing into or being taken from the battery cells.

The variation in in cell voltage on open circuit at various stages of discharge are approximately as follows:-

FIG 8

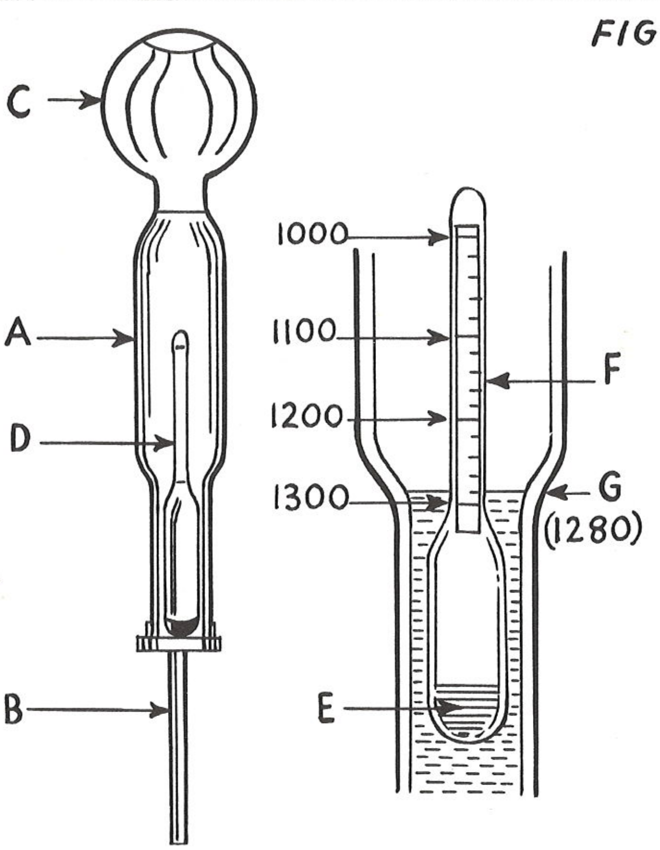

C
1000
A
1100
F
1200
D
1300
G
(1280)
B
E

FIG 9

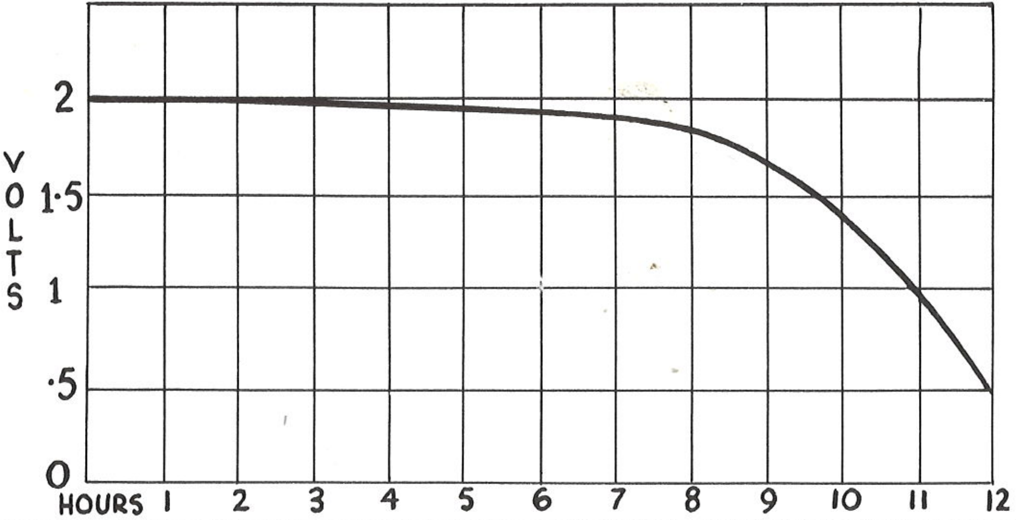
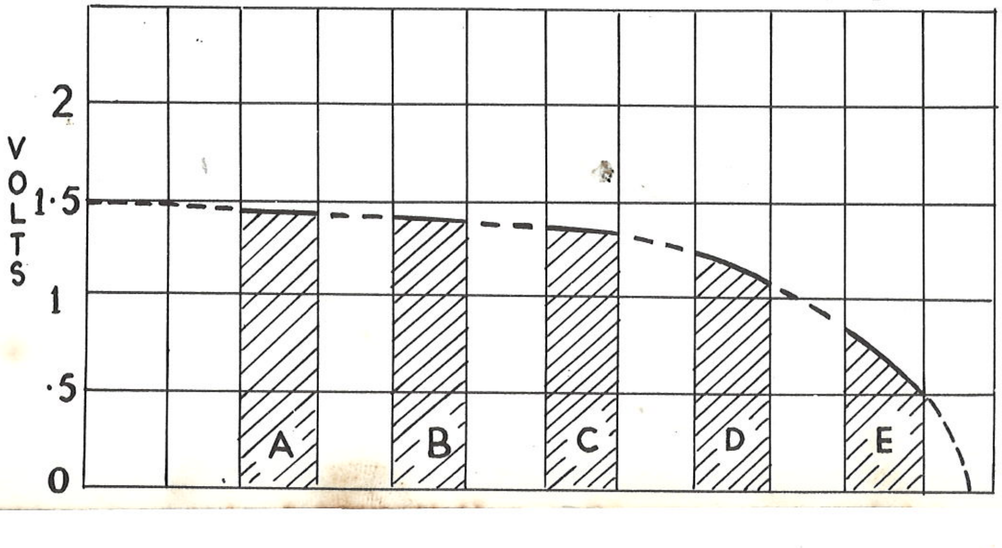


FIG 10



2.17 volts open circuit indicates that cell is 100% charged.
2.10 volts open circuit indicates that cell is approx. 75% charged.
2.06 volts open circuit indicates that cell is approx. 50% charged.
2.02 volts open circuit indicates that cell is approx. 25% charged.
1.95 volts open circuit indicates that cell has very little useful remaining capacity.
1.90 volts or lower open circuit indicates that cell is completely discharged.

In the same way that a measurement of specific gravity enables us to determine within commercial limits the state of charge of a battery cell, so will a measurement of open circuit voltage achieve the same results. As the above figures indicate, however, the variation in voltage is very small and to enable it to be read accurately it is necessary to use an instrument capable of reading within 1/100th volt. This is not possible with ordinary voltmeters and it has previously been necessary to use special laboratory type instruments costing £40. or £50. or even more.

Recently, however, a new type of portable instrument has been developed which incorporates a Wheatstone Bridge Circuit and which is designed to read accurately within the required limits of 1/100th volt. This instrument is the Crypton "HYDROLEK" which will be referred to later.

BATTERY STARTING CAPACITY.

A Hydrometer test of specific gravity or a Crypton "HYDROLEK" test of open circuit voltage will accurately determine whether the battery state of charge is within acceptable limits. Neither test will, however, indicate the starting capacity of the battery, i.e., its ability to supply sufficient power for engine starting. To enable a test of battery starting capacity to be made it is essential to apply a load to the battery equivalent to that which it experiences during starting and to measure battery voltage whilst this load is applied.

Battery starting capacity testing is very important and many operators fail to appreciate its importance and significance. The accompanying diagrams Nos. 9 and 10 will help to make this position clear. Fig.9 shows the gradual fall in voltage of a battery cell on a constant current discharge over a period of 12 hours. The decline in battery voltage is fairly uniform for 8 hours but then falls away rapidly going into a "landslide" from the 10th to the 12th hour.

Fig.10 shows what happens in the case of the starter load where the load is intermittent and only applied for a few seconds at a time. Assuming that the starting periods are on equal load and are of five seconds duration, five periods are shown in the graph (a healthy battery of proper size will provide many more starts than the five indicated). During the first start "A" the voltage of the starter will remain virtually constant for approximately 1.5 volts per cell. During the second start "B" and the third "C" the voltage will decline to approximately 1.3 volts. At the end of the fourth start "D" the voltage has fallen to about 0.8 volts. In the fifth start "E" the voltage drops away steeply to less than ½ volt and the starter will fail even to turn the flywheel. All service men will be familiar with this well known sign of a completely "flat" battery. The starter does not operate on volts only, it requires power in watts which is volts multiplied by amps.

FIG 11

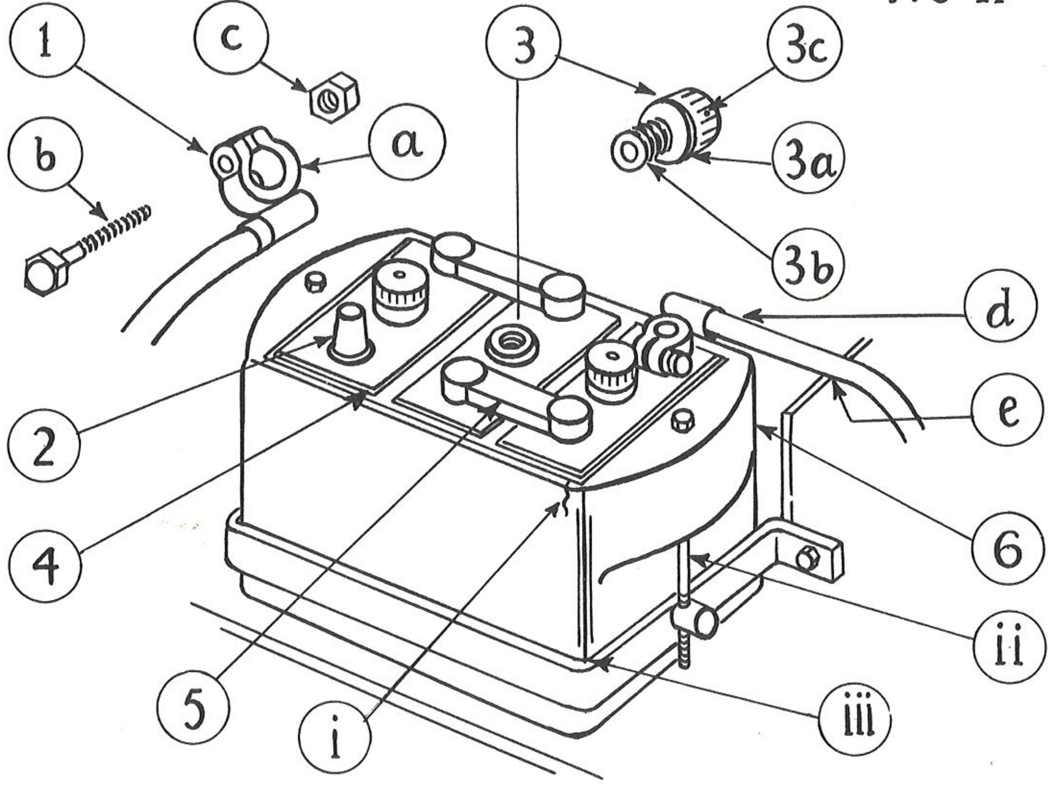

1
c
3
3c
b
a
3a
3b
d
e
2
4
6
ii
5
i
iii

FIG 12

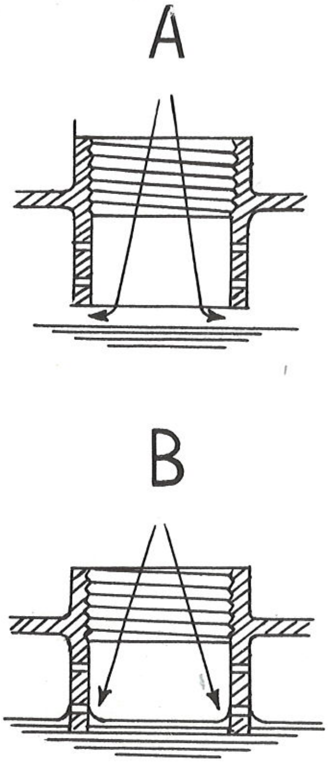
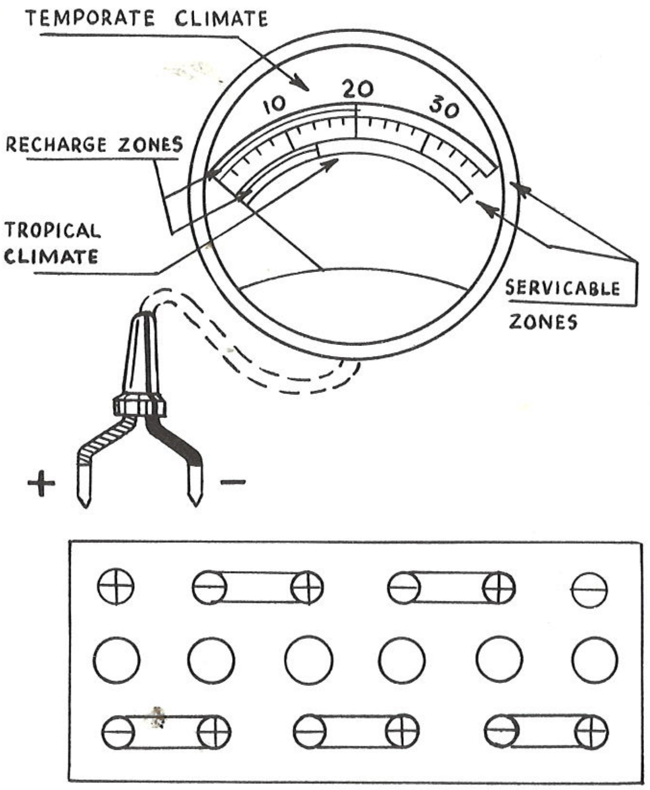


FIG 13


TEMPORATE CLIMATE
10
20
30
RECHARGE ZONES
TROPICAL CLIMATE
SERVICABLE ZONES
+
-

SYSTEMATIC DIAGNOSIS OF BATTERY CONDITION.

We now come to the important business of dealing with the inspection and practical testing of the battery so that we can make reliable recommendations to the car owner. The first step is to make a thorough inspection of all points listed in the preceding paragraph. To make this easy a special diagram is illustrated in which all points needing inspection are illustrated as follows:-

(1) Terminals and Connections. Remove both terminal clamps and inspect thoroughly for corrosion and cable condition.

(2) Terminal Posts. Examine carefully, particularly the positive post and note any corrosion, hard or burned surface, looseness in the lids or distortion.

(3) Stoppers. Check the rubber sealing ring (3A), condition of screw thread (3B), see that vents are clear (3C). See that any special form of gas release valve is free and working properly.

(4) Lids and Sealing. All lids should be level with sealing material not cracked or chipped. There should be no film of wet dirty deposit on the lid surfaces.

(5) Inter-Cell Links. These must be properly burned on which can be checked by gently prising under each with an old screwdriver to check firm connection to the post.

(6) Case Condition. Check for cracks around the top edges, inspect holding rods, nuts and end lugs. See that battery is firmly mounted with no rubbing against the cradle or box. Any white corrosion on adjoining metal work indicates a possibly leaky case which should be investigated.

(7) Check level of electrolyte in each cell which should be about 1/8th above level of separators. Fig.12 shows correct level at "A" and incorrect level (too high) at "B" where the fluid is too high and will prevent escape of gas.

TESTING BATTERY STATE OF CHARGE.

Having inspected the battery it should now be tested for state of charge. Two methods are available (1) Hydrometer test of specific gravity (2) Hydrometer test of open circuit voltage.

Hydrometer Test. Use a good quality Hydrometer, withdraw sufficient electrolyte to float the gauge and note the specific gravity reading of each cell. All cells should be uniform within 25 points. Any cell which reads lower is suspect and the battery should be recharged and a further test made.

FIG 14

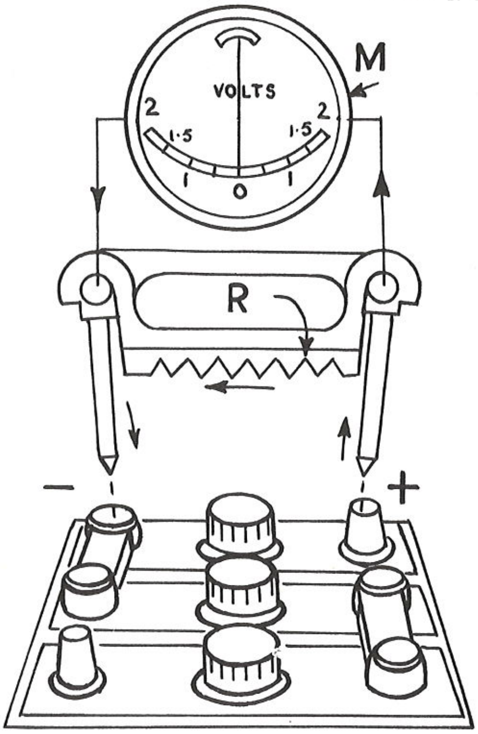
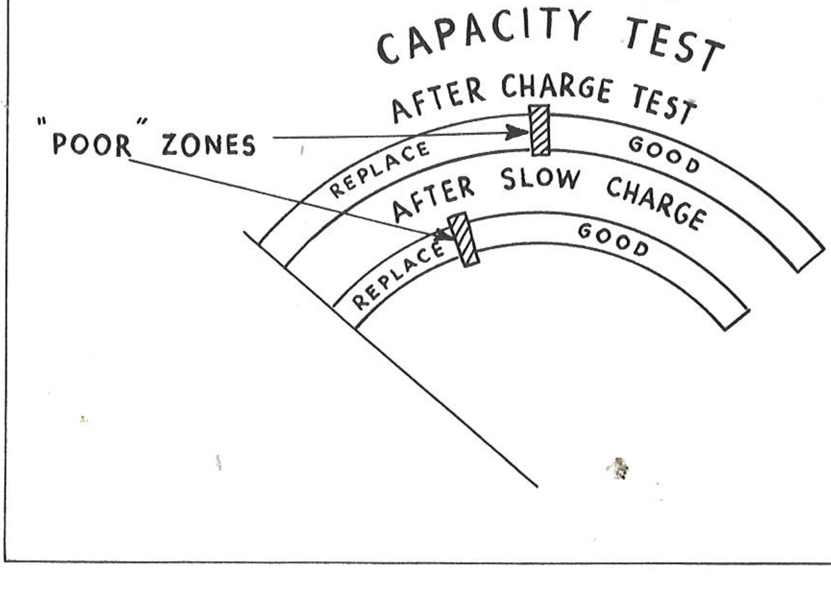

M
VOLTS
2
1·5
1
0
1
1·5
2
R
–
+

FIG 15


CAPACITY TEST
AFTER CHARGE TEST
"POOR" ZONES
REPLACE
GOOD
AFTER SLOW CHARGE
REPLACE
GOOD

"Hydrolek" Test. Fig.13 shows the application of the Crypton "Hydrolek" Open Circuit Voltage Tester. To make the test it is necessary only to place the prods to the terminals of each cell in turn and note the reading of the meter on the colour zoned scale. When properly connected the pointer will swing to the left and then swing over to the right. If incorrectly connected the pointer will swing over and return to the zero position. In this case the connection should be reversed. (No damage will occur by incorrect connection).

A "Hydrolek" gives a correct reading of the state of charge of each cell and indicates on the coloured zone whether the battery is serviceable or needs recharging. All cells should read uniform within six points. If any cell reads six points or more lower than others it is suspect and the battery should be recharged and re-tested.

TESTING BATTERY STARTING CAPACITY.

This is the most important operation in testing batteries because it determines the ability of the battery to start the engine satisfactorily and also shows whether it has adequate starting capacity for continued good service.

A test is made by applying a Tester with a resistance load which will apply a known load current to each cell in turn and simultaneously read the cell voltage.

Fig.14 shows the Crypton Heavy Discharge Cell Tester with its meter "M" and resistance "R". The prods of the pointer are pressed into the terminals of each cell in turn when a current of approximately 180 to 200 amperes will flow through the resistance "R" the voltmeter "M" simultaneously reading the cell voltage. The load should be applied for not less than six seconds when the meter should read 1.5 volts steadily with no visible decline. A weak cell or one nearing the end of its discharge will be revealed by a falling reading. If the test result is seen on cells which the Hydrometer or "Hydrolek" indicated to be suspect, the battery should be removed from the vehicle and given a low rate charge to restore the weak cell. This applies only to batteries which are not nearing the end of their useful life. If the date marking of the battery or the owner informs you that the battery is more than two years old the best advice is to have a new battery.

It is important that high rate discharge tests should be made on batteries only in cases where the state of charge tests show that they are 75% or more fully charged. Any cells which are less than 75% fully charged should be recharged before a high rate test is made.

THE CRYPTON "CAPACITY TEST" METHOD OF TESTING.

The ordinary Heavy Discharge Cell Test is subject to certain disadvantages because the load applied is constant. If the test is made on a battery which is smaller than that for which the constant load was designed the test is too severe and may condemn a battery which is actually healthy. On the other hand if the test is applied to a battery which is larger than that for which the load was designed, the test is too lenient and may indicate a battery to be healthy which is actually in need of charging service. Also the reading of the average type of Cell Tester is not given in terms which the customer can understand.

In order to overcome the above difficulties a special method of starting capacity testing has been developed by Crypton Equipment Limited and incorporated in the Crypton ATC.1260 Fast Charger. This combines a loading resistance suitable for 6-volt or 12-volt batteries with a specially designed meter circuit with special means of adjustment to correct the load for batteries of varying cell capacity. Also the instrument is so calibrated that it would automatically indicate when the battery starting capacity has fallen to limits which make a replacement battery necessary.

Fig.15 shows the scale of the Capacity Test Meter which has three zones (1) GOOD (2) POOR and (3) REPLACE. Full instructions for making the Capacity Test are given with the Fast Charger and the time required is only a few seconds. Any battery with a capacity between 80% and 100% of the normal ampere-hour capacity will read in the GOOD zone. Any battery where the capacity is between 70% and 80% of the original capacity will read in the POOR zone. In all cases where the battery capacity is 70% or less than the original capacity the reading will be in the REPLACE zone. Two scales are provided, one for testing immediately after fast charging when the electrolyte temperature is high and the second for use after slow charging when the electrolyte temperature is lower.

The Crypton Capacity Test feature of the ATC.1260 Fast Charger is a very valuable feature because it enables tests to be made under the variable load conditions which are essential for accurate testing, and has the advantage that the battery condition is expressed in terms which every car owner can understand.

CHARGING METHODS.

Before we conclude this lesson there are some things you should know about the proper way to re-charge batteries which tests show to be in a low state of charge but which are otherwise in a serviceable condition. The best method of recharging depends largely upon the extent of the discharge and also on the time during which the battery has remained in a discharged condition.

Service men frequently refer to cells being "sulphated". In actual fact all cell elements become sulphated, the formation of lead sulphate by electrical action during discharge is a normal part of battery chemical procedure. It is, however, important that discharged cells do not remain in a discharged condition for any lengthy period. If this happens the sulphate starts to crystallise and the normal sulphate coating hardens and locks itself in the pores of the active material on the positive and negative plates. This tends to seal the plate surfaces against contact with free acid and sets up a high internal resistance within the cell. The normal chemical transformation is impeded and slowed down.

If we connect a battery in a sulphated condition we shall find one of two things. Either the charging rate will be low at a given applied voltage or the correct charging rate can only be attained by applying a much higher charging voltage.

In both cases the cell temperature rises sharply due to the insulating effect of the sulphate crystal formation.

The only correct treatment for a sulphated cell is to charge it at a low rate which allows the slowed down chemical process to dissolve the crystals and gradually restore the cell to a healthy condition. This means a long charge which cannot be hurried, care being taken to keep the charging rate to the highest figure that can be permitted but without undue heating up of the cell. A thermometer inserted in the electrolyte and a voltmeter connected across the cell terminal will indicate the progress of the charge. The gradual breaking down of the sulphate will be evidenced by a gradual increase in the charging rate without undue rise of temperature.

Any battery which on test indicates the possibility of defective cells should be given a slow charge for which purpose a rectifier is suitable. Any battery which is known to have been left in a discharged condition for an appreciable period should also be slow charged.

FAST CHARGING.

This is the modern method of dealing with healthy batteries which have become partially discharged in service. The battery can be charged in position on the vehicle with a portable Charger such as the Crypton ATC.1260 Fast Charger which will charge individual 6 or 12 volt batteries in the vehicle at rates up to 80/100 amperes.

Many service men are understandably apprehensive as regards the practicability of charging batteries at these high rates. The method is, however, completely safe provided that the temperature of the electrolyte is not allowed to exceed the manufacturer's limits of 125 degrees F. and charging at the high rate is not continued for too long a period of time. The best method of ensuring a limited temperature rise and correct charging period is through the use of thermostatic control which is a specialised feature of the Crypton ATC.1260 Fast Charger. A thermostat is inserted in the electrolyte before charging commences. As charging proceeds the electrolyte temperature increases slowly at the beginning of the charge but more rapidly towards the end of the charge and at the end of the charging period - usually 30 to 60 minutes - the electrolyte temperature will approach the limit of 125 degrees F. and automatically switch off the Charger.

SUMMARY.

Now to "recap" on what we have explained in this lesson, here are the points on which you must be quite clear:-

(1) The importance of the battery and its functions to proper operation of all other electrical equipment on the vehicle justifies the priority we have given it in this lesson.

The starting point of all electrical diagnosis is a complete check of the battery. Should it be found faulty or substantially "flat", then we must fit a replacement, even temporarily, to ensure that other tests are made against a background of normal voltage reaction and adequate power availability.

(2) Battery Inspection should follow a 'drill' so that you make sure of checking every factor. Good inspection is as important as proper testing, and you must practise observation so that signs of present, or potential, defective conditions do not escape your notice.

(3) The first stage of testing is to measure state of charge in all cells by hydrometer or "Hydrolek" readings. Load tests must not be applied to unchecked cells, as it may prove detrimental, as well as inconclusive, if applied to cells in faulty or low-charged state.

(4) Load tests are to be made on all cells found fit to be so tested. The load must be applied for an equal number of seconds to each cell and the reserve of power available judged by the meter indication during the period of load.

(5) A battery in which all cells show equally low can be regarded as in need of charging. The condition during, and after charging will determine whether the cells are healthy and what further service may be expected from them.

(6) When one or more cells shows a markedly lower condition than the rest, we have evidence of faults in those cells. Recharging and subsequent testing may be advised for batteries still within their designed life period, but if the battery has had over two years service it is extremely improbable that it will continue to give satisfactory service for much longer. A replacement is the best remedy to ensure against breakdown.

In concluding, we would like to add a note concerning the use of the starter as a means of checking voltage on starting load. This really leads on into the next lesson, where we shall deal fully with starter operation, and we would emphasise the point therein raised that we have extremely variable conditions of load due to engine temperature and other reasons. That is why fixed load resistors are used in load testing circuits. Starting a cold stiff engine is battery duty under maximum load, but until we have been through the starting system, we do not know how much load this imposes. Having established battery condition by fixed standards, as this lesson teaches, we are free to test voltage under starter load, when we know that any poor performance we meet will be due to conditions outside the battery or its connections.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 4

THE IGNITION SYSTEM

A Practical Explanation of
Modern Automobile Ignition

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

THE IGNITION SYSTEM

The ignition system has the job of producing and delivering high voltage up to 25,000 volts to the correct plug, in the right firing order and at the right interval of time so that the mixture of properly compressed air and fuel in the cylinder is ignited.

A basic ignition system is illustrated in Figure 1 and comprises a battery "B", ignition switch "I/S", ignition coil "C", distributor with condenser "D", spark plugs "P" and the low tension and high tension wiring.

The source of high voltage in the ignition system is the ignition coil, which increases the battery or generator voltage to the high voltage needed to cause a spark to jump across the spark plug electrodes. The ignition coil has two windings, a primary winding consisting of a few hundreds of turns, and a secondary winding consisting of several thousands of turns, both windings being wound on a soft iron core.

The complete ignition system has two sections - a primary or low tension section and a secondary or high tension section.

IGNITION PRIMARY SECTION.

Figure 2 shows the primary section of the ignition system. When the ignition switch is "ON" and the breaker points "CB" are closed, current flows from the battery positive terminal through the car frame (Earth) at 1 and 2, through cable 3 (or frame connection) to the breaker points "CB", thence via cable 4 to the ignition coil primary winding "PW", leaving the coil via cable 5 and flowing via the ignition switch "I/S", regulator "R", ammeter "A", cable 8 and the starter switch junction "SS" to the battery negative terminal. The system illustrated with the battery positive terminal connected to earth is called a positive earth return system. Some vehicles have electrical systems with the negative battery terminal connected to earth; these are called negative earth return systems and the flow of current is in the opposite direction to that shown in Figure 2.

When the breaker points open with rotation of the distributor cam, the current flow in the primary winding of the ignition coil is quickly stopped. This induces a high voltage in the secondary winding of the coil.

When the points open, the current flowing in the primary section tries to flow across the points as they part. Under ordinary circumstances this would cause arcing to take place between the contact points and would also draw off some of the energy from the coil causing a reduced voltage and weak ignition. This arcing is prevented by the condenser which absorbs the current - provides a place for it to flow - and also has the important effect of causing the current in the coil primary to stop very quickly; this increases the voltage generated in the coil.

FIG.1.

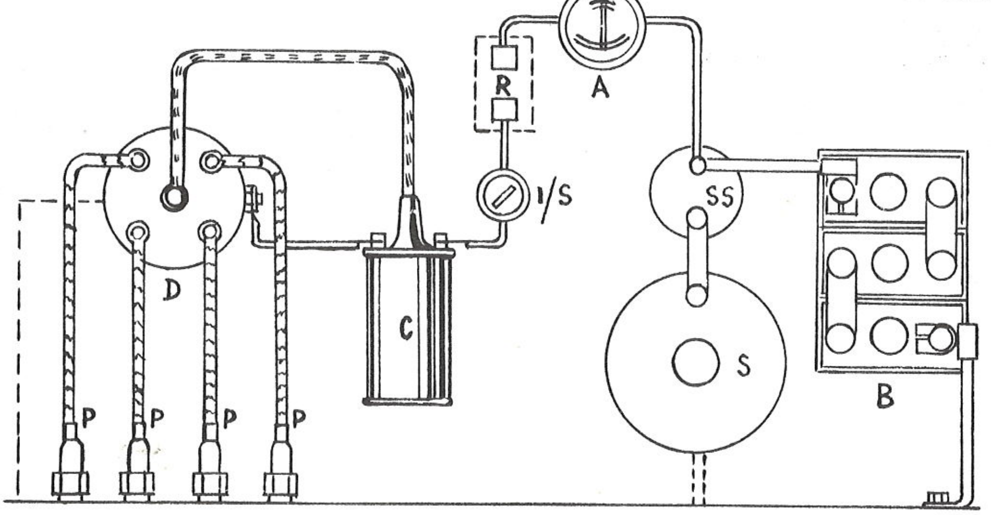

A
R
I/S
SS
D
C
S
B
P
P
P
P

FIG.2.

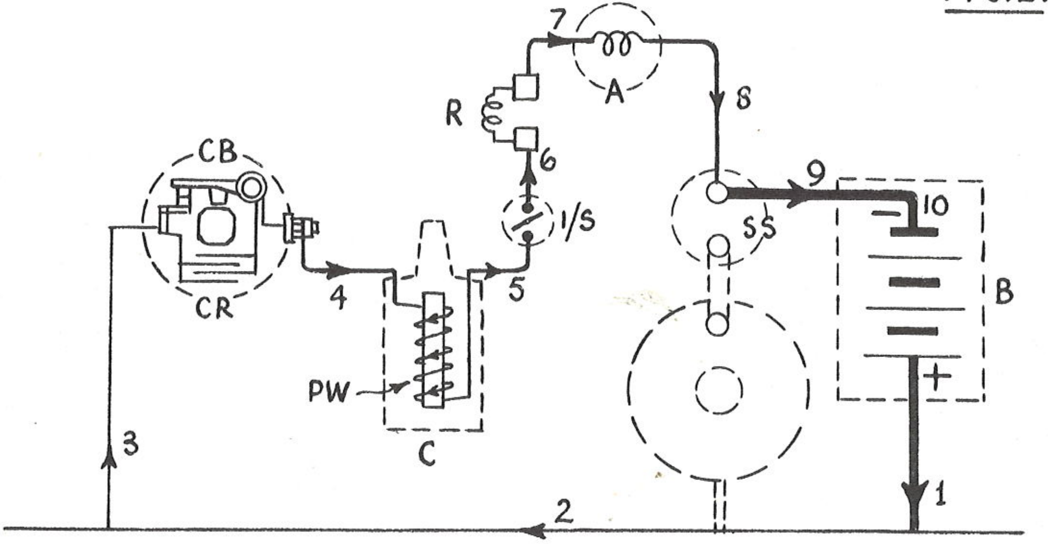
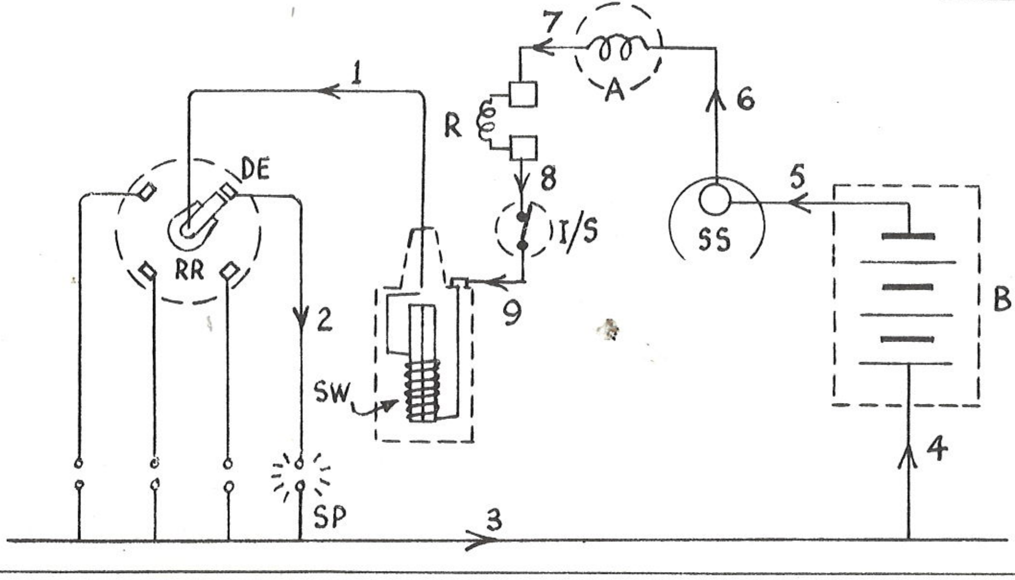

7
A
8
R
6
CB
9
10
—
I/S
SS
CR
4
5
B
+
PW
C
3
1
2

FIG.3.


7
A
1
6
R
DE
5
8
I/S
SS
RR
2
9
B
SW
4
SP
3

IGNITION SECONDARY SECTION.

Figure 3 illustrates the secondary section of the ignition system. A high voltage is generated in the ignition coil winding "SW" and flows from the coil H.T. terminal through cable 1 to the distributor rotor "RR", jumps across the gap between the rotor and the distributor electrode "DE" and then flows via the H.T. cable 2 to the spark plugs "SP". The current then flows via earth 3, through the battery "B", cable 5, junction "SS" and via 6-A-7-R-8-I/S back to the ignition coil via cable 9. Most British vehicles are of the type illustrated. In some U.S.A. vehicles, however, the return path is taken direct from earth to the coil casing to which the other end of the coil "SW" winding is connected.

It will be noted that the high tension current in the system jumps across two gaps in the form of a spark. The first gap is between the distributor rotor and electrode and the second across the spark plug electrodes.

HOW THE HIGH VOLTAGE IS GENERATED.

Figure 4 shows the ignition system in simple basic form. The coil primary winding is shown at "P" and the secondary winding at "S" both coils being wound on a common soft iron core "I". The distributor breaker points are shown at "CB", the condenser at "CR", the battery at "B", and the spark gap at "SG".

When the breaker points "CB" are closed current flows in the coil winding "P" and sets up a magnetic field around both coils and the iron core.

The current in the primary winding does not grow instantaneously to its full value; its growth is gradual as shown at "P" in Figure 5. This growth of current in the coil primary winding causes the magnetic field in the coil to grow in strength, and the increasing lines of magnetic force cause a current flow in the primary winding which is seen at "S" in Figure 5; this current is in the reverse direction to that in the primary coil.

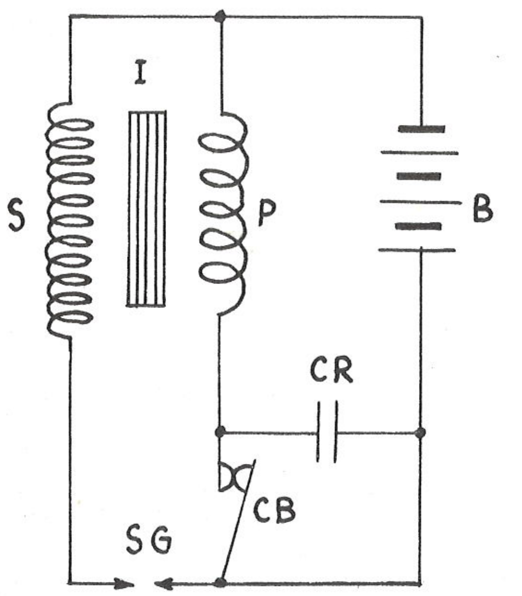
When the points open the current in the primary coil which would normally fall slowly and continue across the points as an arc flows into, or "charges" the condenser. Immediately the condenser is charged or "filled up with current" it discharges - that is, the current flows out of the condenser again and back into the coil primary winding. This reverse flow of current from the condenser stops the current flow in the primary winding very quickly. This causes the magnetic field to collapse suddenly. This is exactly what we want because the quicker the collapse of the magnetic field the higher the voltage generated in the coil "SW" winding. This high voltage is seen at the right of "S" in Figure 5 and gives us the high voltage we want to flow through the distributor to the plugs, causing a spark to jump across the plug electrodes.

Everything we have described happens every time the points are closed and opened and takes place with great rapidity. In the case of an 8-cylinder engine at 60 m.p.h. the distributor breaker points are closed, current flows through the primary winding and builds up a magnetic field, the points are then opened, current in the primary winding charges the condenser, the condenser then discharges causing the flow of current to stop quickly, the magnetic field suddenly collapses, and generates a high voltage in the coil secondary winding, which is delivered via the distributor to the spark plugs, in approximately 1/200th of a second.

IGNITION COILS.

Ignition coils must be of exactly the right types to meet the designer's

FIG.4.



I
S
P
B
CR
CB
SG

FIG.5.

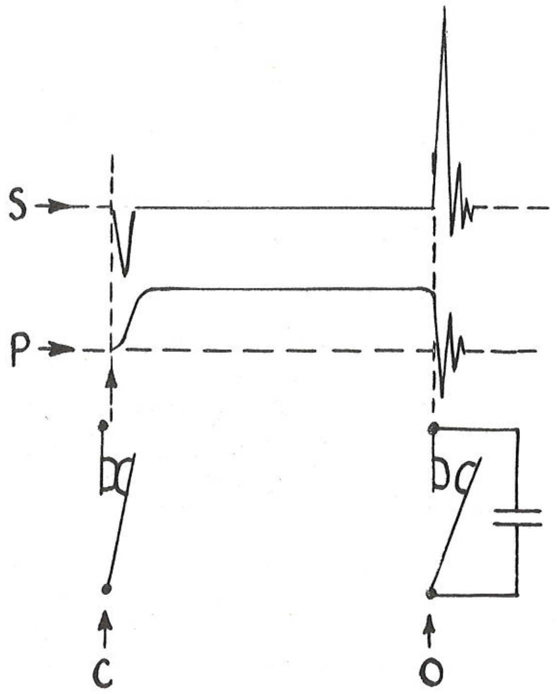


FIG.6.

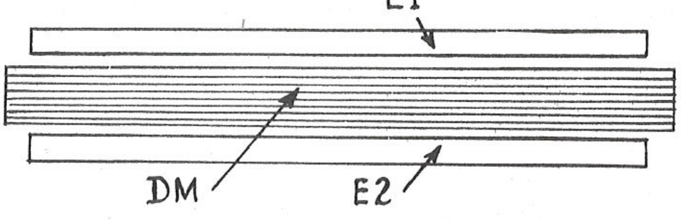
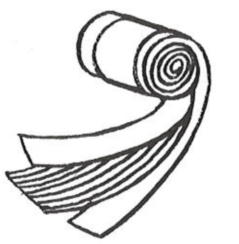


FIG.7.



specifications. They have to provide the voltage needed for efficient ignition which may be as much as 25,000 volts at 10 miles an hour and 15,000 volts at 70 miles per hour.

Great care is taken by engine designers to select a coil of the correct characteristics to suit the engine and to provide the ignition voltage needed for efficient operation under all normal conditions. The actual voltage needed from the coil is variable according to many conditions. The voltage needed at the plugs themselves may vary from approximately 4,000 to 15,000 volts. The exact voltage required will depend upon engine compression and speed, the width of the spark gap and condition of the spark plug electrodes, the air fuel ratio and the spark plug temperature.

It is essential, however, to provide a voltage at the coil over and above that needed at the plugs. This is needed to compensate for conditions which will increase the voltage needed at the plugs such as wearing of the plug electrodes, oxidisation of breaker points, leakage of current from H.T. cables, etc.

The voltage available from the ignition coil varies with the engine speed and the voltage reduces as the engine speed is increased.

The condition of the distributor contact points has an important bearing on the voltage obtainable from the ignition coil. After accumulated hours of use the distributor points become oxidised and this lowers the voltage available at lower engine speeds and may result in misfiring. It is advisable always to check and clean the distributor points each time the engine is serviced and to replace the points at intervals of 10,000 miles.

The spark plug gap also has a very important bearing on ignition voltage. As a result of wear the spark plug gaps increase; this demands a higher voltage from the coil. If the plugs are not correctly regapped the ultimate voltage needed may be higher than the potential voltage output of the coil and misfiring will occur. Also, the condition of the electrodes is important; after use the electrodes tend to become rounded instead of having sharp corners which are necessary for good performance.

It is always important to check and regap plugs at frequent intervals and also to file off the rounded end of the plug electrode. New plugs are advisable at intervals of 10,000 miles.

Another factor often overlooked is the effect of the air fuel ratio on the voltage required for ignition. Where air fuel ratios are lean, a much higher ignition voltage is required. In some cases this may be 33-1/3rd per cent. or more above normal ignition voltage requirements.

TESTING IGNITION COILS.

The easiest and quickest method of testing an ignition coil is to measure its performance with an instrument which makes a direct measurement of the output of the coil against a definite load calibrated to suit the coil characteristics.

This is the method used with the Crypton Coil Tester which, when connected to the ignition coil independently of the rest of the ignition system will operate the coil under the same conditions as on the vehicle, apply a load to the coil and then indicate its output on a clearly zoned meter scale calibrated "GOOD" and "BAD".

It is important that coils are tested under the same temperature conditions as experienced on the vehicle. The Crypton Coil Tester has the facility of heating ignition coils as well as testing them. After making a direct test of the coil output cold, a simple adjustment of the Coil Tester will heat the coil and the test can be repeated with the coil at normal operating temperature.

Testing ignition coils with the Crypton Coil Tester is a very simple process and the results are accurate and can be obtained very quickly.

THE CONDENSER.

The ignition condenser is illustrated in Figure 6 and consists of two long thin metallic foil strips shown at "E1" and "E2", and a slightly longer and wider strip of insulating material shown at "DM". This material serves as an insulator in separating the two metal strips but must also withstand high voltage electrical charges.

Figure 7 shows how the elements are assembled with one metal strip above and one be-low the insulating strip, the three being rolled into the form of a cylinder. The complete cylinder is placed in the familiar metal can with one strip connected to the can and the other to the insulated end terminal as shown in Figure 8.

The condenser is connected across the distributor contact points to prevent arcing across these points when the contact points first open by providing a place where the current can flow until the points are freely separated. The condenser also has another important effect of causing the flow of current in the primary winding to stop suddenly, which increases the value of the secondary voltage. If the condenser were not fitted, arcing would take place which would rapidly burn the points, and the value of ignition voltage would drop, causing weak ignition. In practice, failure of the condenser will result in a progressive breakdown of ignition, due to burning away of contact points and failing spark energy.

TESTING THE CONDENSER.

Three tests have to be made to determine condenser condition and efficiency. These are:-

(1) Capacity
(2) Series resistance
(3) Insulation

CAPACITY TEST. The purpose of this test is to determine whether the condenser is of the correct capacity for the vehicle to which it is fitted and to verify that the condenser electrodes (metallic foil strips) are able to absorb the current flow - in other words whether the condenser has adequate capacity. If the connection to the terminal or can is broken, or one of the strips is broken or separated part way along its length, then the capacity of the condenser is reduced and it will fail to absorb the current sent into it with the result that the surplus current will cause arcing and burning of the contact breaker points.

Condensers which have incorrect capacity will cause pitting of the breaker points. If the condenser capacity is too low pitting will occur in the negative distributor contact point; if the condenser capacity is too high pitting will occur in the positive distributor contact point.

Condenser capacity is measured in terms of microfarads, the larger the reading in microfarads, the larger the capacity of the condenser.

It is a simple matter to test condenser capacity with a modern Condenser Tester which gives a direct reading of the capacity in microfarads. The Crypton Condenser Tester makes this test and all other tests needed on a single instrument.

SERIES RESISTANCE TEST. The series resistance test of the condenser is extremely important. Its purpose is to determine whether there is adequate contact between the condenser lead and one of the two layers of foil and also whether there is good contact between the other layer of foil and earth.

At the instant the contact points separate the high surge of voltage causes an appreciable current to flow into the condenser in building up the charge on its electrodes - although no current actually flows through the condenser. This can be understood by referring to Figure 9 in which the water pressure "P" in a pipe line is impressed on a closed tap "T". If we open the tap suddenly (equal to separating the distributor points) the pressure will drop as water rushes into the sealed reservoir "R". The rise of the water level in the reservoir will increase the air pressure above it and the flow will decline in proportion as air pressure rises to equal the incoming water pressure. At this point of equality of pressures the water flow will cease. How long this will take depends upon the size of the reservoir and the bore of the pipe line. In the same way, the capacity of the condenser (size of reservoir) and its series resistance (bore of pipe) determines the time the condenser will take to absorb the electrical charge. High resistance between either of the condenser electrodes and the point to which they are connected will have exactly the same effect as a restricted pipe line in the water analogy illustrated in Figure 9.

Figure 10 shows in diagram form how a resistance "R" will limit the rate or speed at which energy enters the condenser. The current will take longer to flow from the open points "CB" to the condenser elements "C" because of the resistance "R". In practice this will have little effect at nominal speeds, where the frequency of make and break of the distributor points are low and when there is reasonable time for the charge to build up. At higher engine speeds where the distributor point frequency is greater, the condenser will fail to absorb the full charge or to give a complete discharge; the result will be a loss of high voltage, a weakened spark and intermittent misfiring.

We have given the above information in detail because we want to stress how very important it is to test the series resistance of the condenser. Under normal conditions this is a difficult test to make because a special oscillatory type of test circuit is needed. Such a circuit is built into the Crypton Condenser Tester which with a simple switching operation, gives an accurate indication of whether the series resistance of the condenser is within acceptable limits.

INSULATION. This test determines the quality of the insulating material between the layers of foil in the condenser. If the insulation is weak or "leaky" the charge will leak away from one layer of foil to the other. The result will be that the charge is not held as it should be and will leak across the fault in the insulation. The current in the low tension ignition circuit will not be interruped as suddenly as is essential for good spark generation, and weak ignition will result. In practice, weak insulation causes the ignition to miss under high compression. A complete breakdown of the insulation will cause the two layers of foil to touch, and will short circuit the distributor contacts thereby causing complete failure of the ignition system.

FIG. 8.

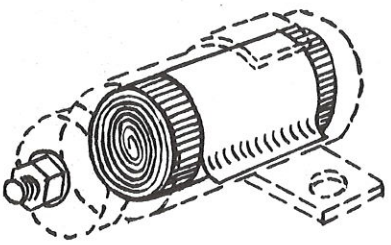


FIG. 9.

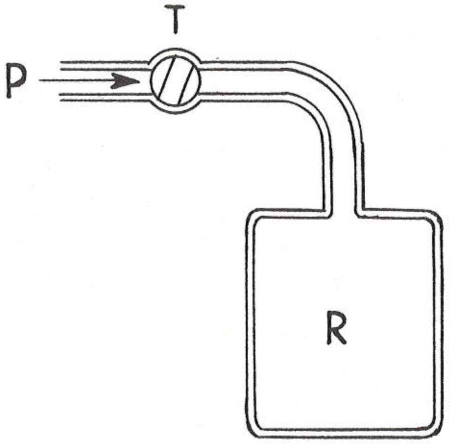


FIG. 10.

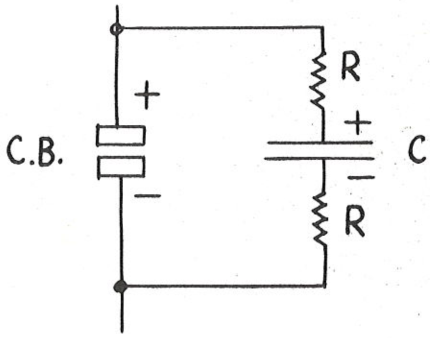


FIG. 11.

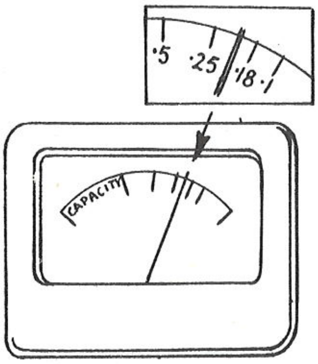

·5
·25
·18
·1
CAPACITY

FIG. 12.

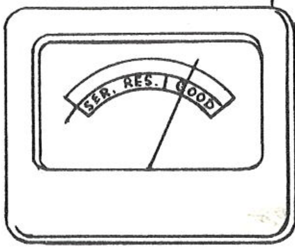

SER. RES. | GOOD

FIG. 13.

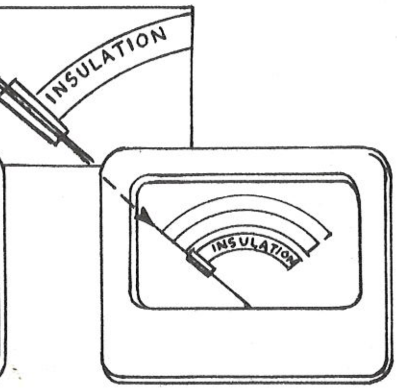
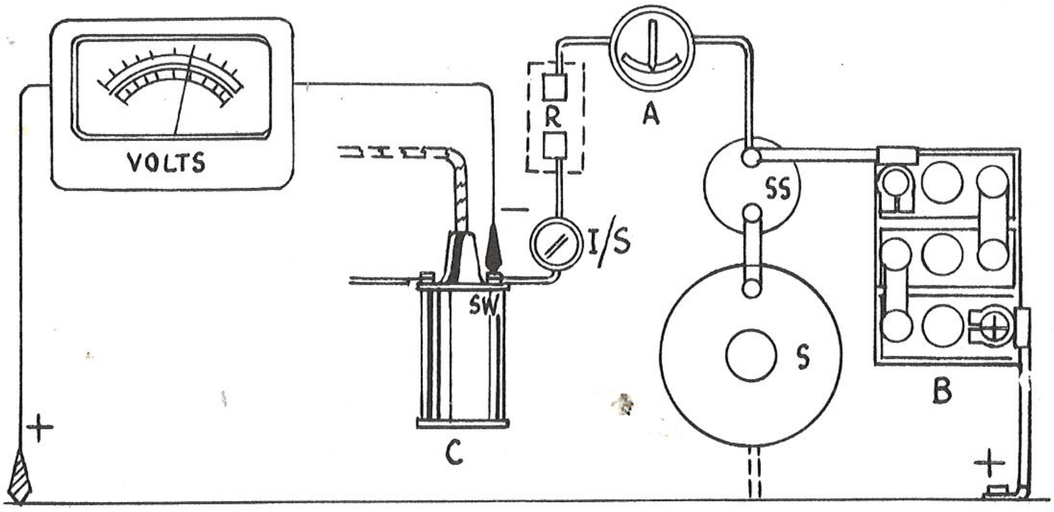

INSULATION
INSULATION

FIG. 14.


VOLTS
R
A
SS
I/S
−
SW
S
B
C
+
+

It is therefore essential to make a proper test of the insulation of the condenser. This test, with the previous tests of the capacity and series resistance, is incorporated in the Crypton Condenser Tester.

SEQUENCE TESTING.

Figures 11, 12 and 13 illustrate meter readings indicating a good condenser. Figure 11 shows capacity of approximately 0.2 Mfd. Fig.12 shows series resistance "GOOD" and Fig.13 indicates insulation in the "GOOD" zone of the scale.

SPARK PLUGS.

The function of the spark plug is to carry the high tension current to the combustion chamber so that there is no leakage of the high voltage applied to the plug and no loss of compression.

Not only must plugs be in good condition, they must also be of the correct size and heat range to suit the engine to which they are fitted. It is important when servicing engines always to check and verify that the plugs are of the type and also of the heat range specified by the engine or sparking plug manufacturers.

When carrying out ignition diagnosis it is important to make a careful visual inspection of the spark plug which will give the experienced operator a good indication of general operating conditions.

Plugs with insulators which are very dark brown or black indicate the possibility of a rich mixture, excessive choking or plugs which are too cool.

Plugs with insulators which have a greyish appearance, or which are "blistered", indicate that the plugs are running too hot.

The insulators of plugs of the correct heat range will have a light brown tan and be fairly smooth.

It is important that plugs are properly cleaned at regular intervals and this is particularly necessary with modern high compression engines using present day high octane fuels. Spark plugs need cleaning and re-gapping at intervals of a minimum of 5,000 miles and it is advisable to replace plugs at intervals of 10,000 miles.

IGNITION SYSTEM DIAGNOSIS.

The most effective method of testing the ignition system is to make a series of orderly sequence tests based upon a logical process of elimination. This is easier and quicker than jumping to conclusions and making haphazard and experimental tests based on speculation. It is also a mistake to confine the diagnosis to the ignition system and assume that everything else is good.

As an example of this, a car owner may complain that starting is sometimes difficult and there seems to be an intermittent misfire. Many operators would jump to conclusions and possibly announce "it probably needs new plugs", or "the condenser needs replacing". In some cases few guesses could be farther from the truth. What about the distributor contacts, cap and rotor, wiring, cables, connections, battery, switch contacts, ammeter and its connections, carburettor condition, fuel feed, manifold gaskets, valves, pistons and rings? Any of these may be responsible for the complaint of poor starting and a misfire. Obviously a complete diagnosis is the only answer and any so called "short-cut" method

FIG.15.

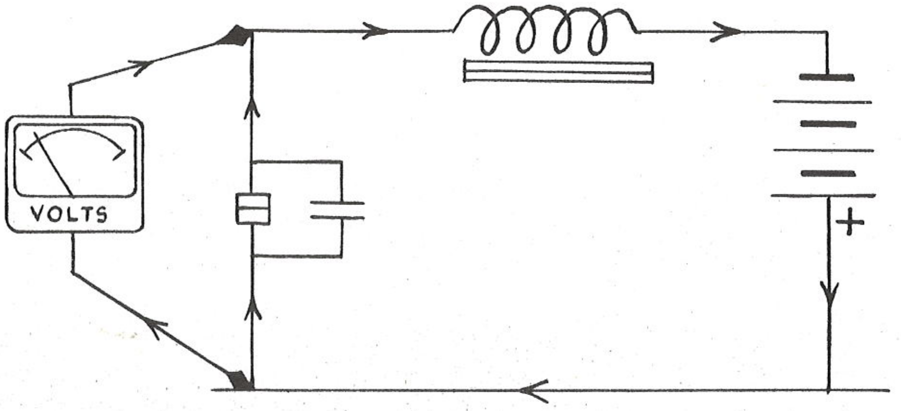
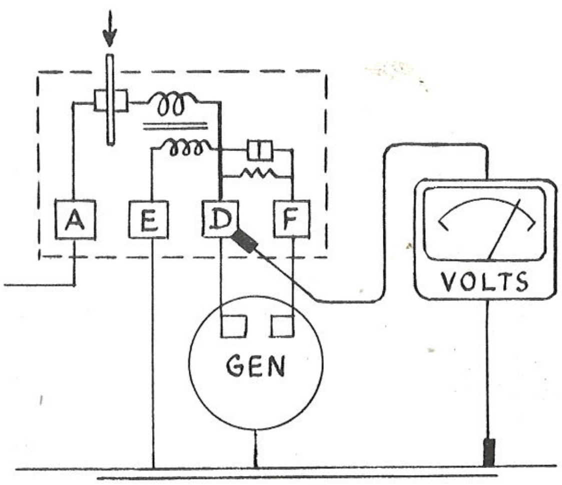


FIG.16.


A
E
D
F
GEN
VOLTS

involves the risk of worry and trouble, waste of labour and material, delay and disorganisation, irrecoverable expense and the loss of both the present and future business of the customer.

It is because of this that we so strongly advocate a systematic test of the entire engine whenever it is necessary to deal with a complaint of impaired engine performance. The system for testing the entire engine is described in Lesson 6. This comprises a complete systematic test of the entire ignition system and a similar systematic test of the remaining performance divisions - compression and carburettion.

Apart, however, from the tests included in the systematic ten-point test procedure, there are a number of practical points which need to be properly understood and carried out. To help all students the following information is therefore given.

THE BATTERY.

Always start an ignition system check by testing the battery state of charge and startability voltage. A hydrometer, or preferably the Crypton "Hydrolek" will accurately show the state of charge of all cells, and a Heavy Discharge Cell Tester will give a reliable indication of battery starting voltage. Do not forget to make a careful visual inspection of the battery.

VOLTAGE AVAILABLE AT COIL.

Any voltage loss in the circuit between the battery and the ignition coil will cause faulty ignition performance and hard starting. The voltage loss can be easily tested by connecting a voltmeter between the ignition coil "SW" terminal and earth as in Fig.14. The voltmeter should read not less than $\frac{1}{2}$ volt lower than the full battery voltage, i.e., 11.5 volts on a 12-volt system and 5.5 volts on a 6-volt system. The contact points must be closed when making this test.

DISTRIBUTOR BREAKER POINTS.

The distributor breaker points must be in good electrical condition. The voltage loss across the points can be easily tested by connecting one voltmeter lead to the distributor "CB" terminal and the other voltmeter lead to earth. With these connections the voltmeter is connected across the points as shown in Fig.15. With the points closed the voltage reading must not exceed 1/10th volt.

IGNITION VOLTAGE ON CHARGE.

A test should be made by noting the voltmeter reading with the generator charging. With the voltmeter connected to the ignition coil "SW" terminal and earth the engine is started and the rise in voltage noted. As the engine speed is increased the voltmeter reading will rise. If the generator is out of action for some reason then the voltage will remain practically unchanged as the engine speed is increased. An excessively high voltage indicates the possibility of a faulty setting of the regulator. This must be corrected because the high voltage will cause overloading of the primary winding of the coil, will impose a stress on the condenser and the H.T. side of the ignition system and will cause trouble due to burning and pitting ot the breaker points especially at low speeds.

VOLTAGE REGULATOR SETTING.

A check should also be made to verify the correct setting of the voltage regulator. Figure 16 shows the connections for testing Lucas voltage regulators with one voltmeter lead connected to the control box "D" terminal and the other lead to earth. The cutout contacts are separated by a strip of insulation as indicated. The engine is run at a fast idle (1,200 - 1,500 r.p.m.) and the voltage should rise to - an average of 8 volts for a 6-volt system or 16 volts for a 12-volt system. If the voltage reading is outside these limits - after checking with manufacturer's figures - the regulator needs adjustment. If it fails to respond to adjustment a replacement unit is needed.

IGNITION COIL.

The ignition coil should be tested with the Crypton Coil Tester and a check made with the coil hot as well as cold.

In addition to testing the ignition coil electrically with the Coil Tester, a careful inspection should be made of all terminals and moulded insulation parts. Facilities are provided in the Crypton Motor Analyser for making an electrical test of moulded insulation parts of the coil and also the distributor cap and rotor.

A check can quite easily be made of the ignition switch by disconnecting the distributor low tension lead from the coil and connecting an ammeter to this lead and to the coil primary terminal. The ammeter reading should not exceed 2.5 amps. on a 12-volt coil and 5 amps. on a 6-volt coil. With the ignition switch turned on and off several times the ammeter reading should be the same each time. If not it indicates that the ignition switch is faulty. If no reading is obtained when the switch is turned on and the coil has not been tested carefully, check it with the Coil Tester. Also check that distributor contact points are closed.

CONDENSER.

A complete test should always be made of the condenser. If the condenser is deficient in capacity, series resistance or insulation, it will cause failure of the ignition system.

POOR HIGH TENSION INSULATION.

Efficient insulation in the high tension is essential. All cables should be carefully inspected for cracks, punctures, or oil soaking. Both the distributor cap and rotor should be carefully checked and examined for burned tracks or carbon runners. The Crypton Motor Analyser is fitted with a high voltage tester which enables an electrical test to be made both of the distributor cap and rotor and the high tension cables.

SPARK PLUGS.

Spark plugs should always be thoroughly cleaned, carefully tested and re-gapped. If the plugs are badly burned or the porcelains cracked, new plugs should be fitted. Adjust the gaps in strict accordance with the manufacturer's specifications.

BE THOROUGH.

If tests are carried out thoroughly as described in this Lesson it will ensure that the entire ignition system has been quickly and accurately tested. All units will have been tested under load conditions equivalent to those experienced in normal service. Tests will have been made with instruments all specially designed for their individual purposes and all test results will have been visibly recorded.

Finally, we repeat that whenever you are called upon to deal with a complaint of engine performance, do not restrict tests to the ignition system only or to any of the other individual performance divisions. Always remember that faulty conditions can be due to ignition, compression or carburettion - or a combination of any two or all three of these divisions.

Always be thorough - test all performance divisions - following the procedure explained in detail in Lesson No.6.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 5

DISTRIBUTORS

An Explanation of the Principle and Operation of Modern Distributors

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

DISTRIBUTORS

The part played by the distributor in engine performance is so important that a special lesson is devoted to the purpose of explaining distributor functions and the procedure for maintenance and testing.

The distributor has three main functions to perform:-

(1) To interrupt the flow of primary current in the ignition coil by the operation of a cam which opens and closes the breaker points at precisely the right intervals.

(2) To distribute the secondary high voltage through the rotor and distributor cap which act as a rotary switch distributing the high voltage to the correct plugs at the right time.

(3) To vary the timing of the spark automatically as required by engine speed and load conditions.

The distributor must perform these functions at extremely high speed and within time settings measured within hundredths of a second. There must be no loss of current through the contact breaker and no loss in the distribution of high voltage.

To understand distributor operation it is necessary to appreciate the relationship between the speed and rotation of the distributor spindle to the engine.

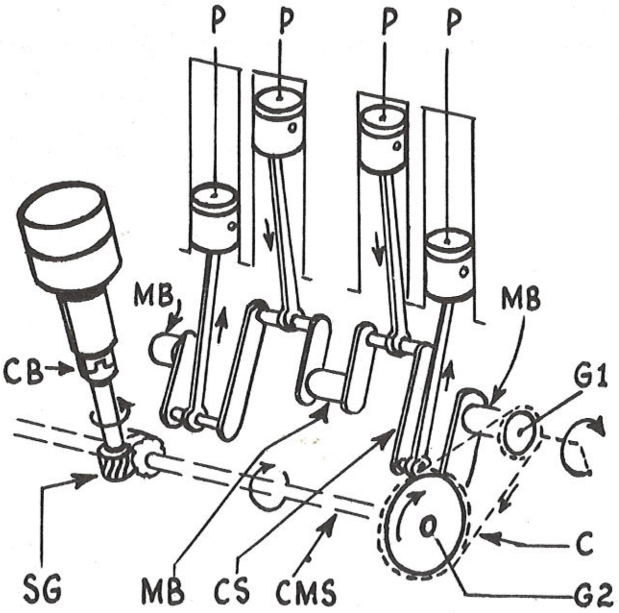
Figure 1 shows the crankshaft "CS" of a four cylinder engine carried in main bearings "MB" coupled to a camshaft "CMS" by chain wheels G1 and G2. The pistons "P" are shown at the commencement of their respective strokes. The distributor driving shaft is driven through the gears "SG" in the direction of the arrow. Each crank of the engine performs two revolutions for each firing impulse and all cylinders must fire in correct rotation at equal intervals with the valves opening and closing once in every two revolutions. The crankshaft completes two revolutions to each cycle, and the distributor one revolution to complete its full cycle. The distributor is, therefore, geared to run at half crankshaft speed. This means that one degree of distributor cam rotation equals two degrees of engine flywheel rotation.

Some distributor specifications are listed in terms of engine r.p.m. - others in distributor r.p.m. It is important to distinguish between the two methods when servicing distributors.

Figure 2 shows typical firing sequences. A 4-cylinder engine fires one cylinder in every 90° the sequence most common being 1-3-4-2 as shown at "4" The six-cylinder engine sequence illustrated fires one cylinder every 60° the sequence shown at "6" being 1-5-3-6-2-4. The eight-cylinder engine shown at "8" fires one cylinder in every 45° the sequence being 1-5-3-7-4-8-2-6.

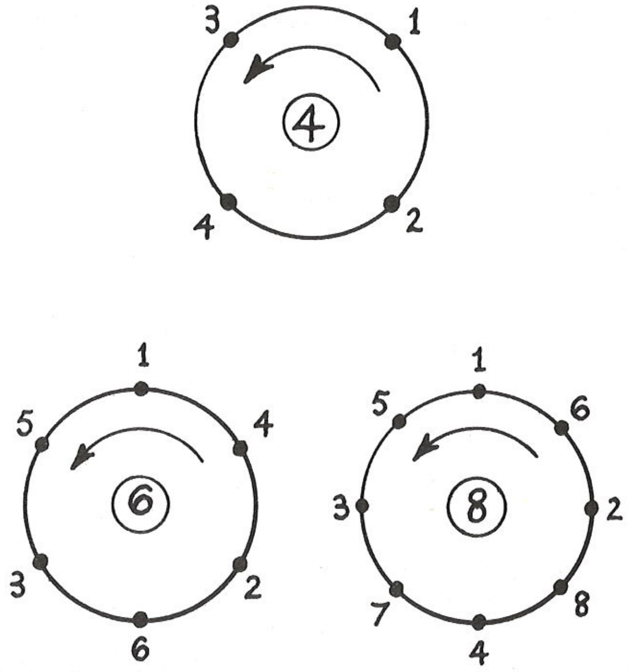
The distributor contact breaker must interrupt the low tension circuit a number of times equal to the number of cylinders during each spindle rotation and direct the high tension to the plugs in the correct order as the pistons reach their firing positions.

FIG.1.



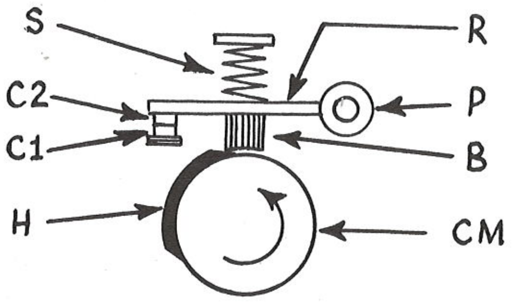
P
P
P
P
MB
MB
CB
G1
C
G2
SG
MB
CS
CMS

FIG.2.



3
1
4
4
2
1
5
4
6
3
2
6
1
5
6
3
8
2
7
8
4

FIG.3.



S
R
C2
P
C1
B
H
CM

FIG.4.

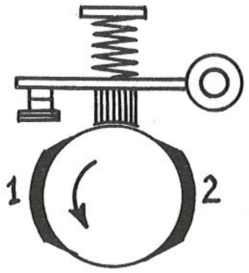
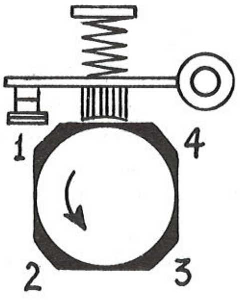


FIG.5.



DISTRIBUTOR SECTIONS.

There are two electrical sections in the distributor:

(1) Primary Section comprising the breaker contacts and condenser, the contacts carrying the ignition L.T. circuit.

(2) The cap and rotor in the Secondary Section carrying and distributing the high voltage to the sparking plugs.

THE DISTRIBUTION L.T. CIRCUIT.

Figure 3 shows the essentials of a simple cam-operated contact breaker. The cam "CM" is rotated by the spindle in the direction shown. The cam lobe is shown shaded at "H". A rocker in the form of a blade "R" is pivotted at a fixed point "P" and has a contact "C2" at the other end which is held against a fixed contact "C1" by the spring "S". The block "B" fixed to the rocker arm just clears the cam but is lifted by the lobe. When this happens the contacts separate against spring pressure and are held open while the lobe passes under the block, the contacts again closing by spring pressure when the lobe has passed the block.

The simple cam illustrated lifts the rocker once per distributor spindle revolution. We must have as many lobes as cylinders, all lobes being similarly shaped and equally spaced. Figures 4, 5, 6 and 7 show the basic design for 2, 4, 6 and 8 cylinder engines. The lobes are numbered but - these numbers do not respond to the firing order. Notice that the block becomes narrower for multi-lobe cams.

The rocker in the 8-cylinder distributor illustrated in Figure 7 lifts eight times for every revolution of the spindle. At high speed this represents extremely rapid operation and makes it difficult to overcome spring lag and inertia. Because of this difficulty an alternative type of breaker unit is sometimes used as illustrated in Figure 8. Two rockers "A" and "B" are operated by a 4-lobe cam so positioned that one is on the peak of the lobe and the other half way between two lobes. The two rockers are connected in parallel and are so timed that one opens its contacts before the other closes. If the numbered lobes are followed in conjunction with the rocker letters it will be seen that there are eight breaks in one revolution but each rocker operates four times. The rockers must be identical in form and lift and the angle between the mounting points must be 135° as shown.

Figure 9 shows the same principle applied to a six-cylinder engine. In this design a 3-lobe cam operates two rockers 90° apart. In some designs two rockers are used in a distributor having a cam with the same number of lobes as cylinders. These rockers are set to break simultaneously in parallel or timed to overlap slightly to provide a longer closed contact period.

CAM DESIGN.

It was explained in the previous lesson that a quick break of the ignition primary circuit is essential to provide good ignition. The rate of break of the contact breaker and the capacity of the condenser combine together to determine the peak voltage generated in the coil secondary winding and delivered to the plugs. The shape of the cam lobe has a marked influence on the rate of break. This is illustrated in Figure 10 where "CL" shows a cam lobe moving in the direction of the arrow. The contact breaker block (or rubbing block or "heel") rides clear of the cam face until its leading edge meets the rising face of the lobe. The point at which this occurs is decided by the contact adjustment and the height of the

FIG.6.

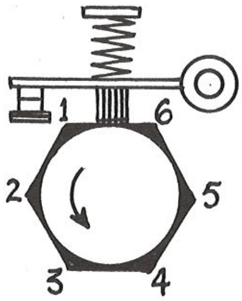


FIG.7.

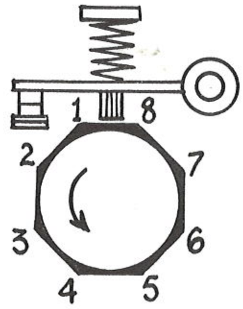
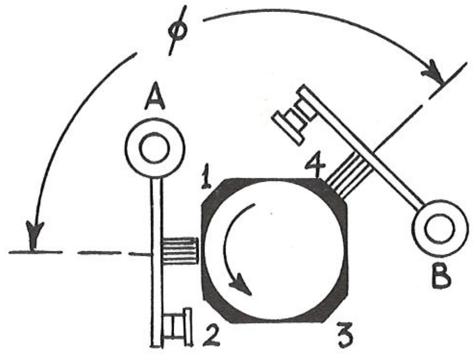
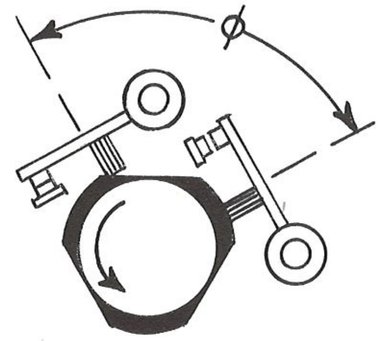


FIG.8.



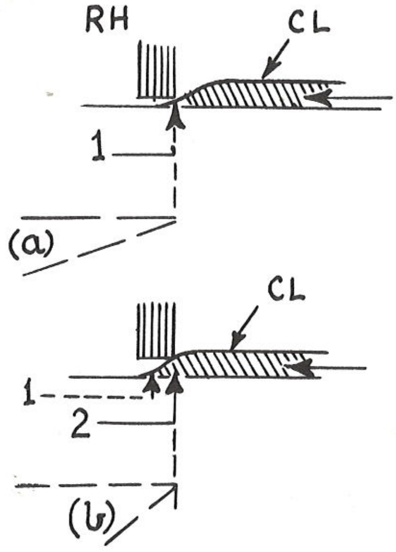
$$\phi = 90^\circ + \frac{90^\circ}{2} = 135^\circ$$

FIG.9.



$$\phi = 60^\circ + \frac{60^\circ}{2} = 90^\circ$$

FIG.10.


RH
CL
1
(a)
CL
1
2
(b)

heel above the cam face when the contacts are closed. If the heel is set low it will meet the lobe face at point 1 in the upper diagram of Figure 10 - the slope of the cam face is indicated by angle (a). If the heel is set higher it will not meet the lobe face until point 2 in the bottom of Figure 10, giving a wider angle as at (b). The steeper angle (b) means a more rapid rate of lift and a quicker opening of the contacts. The timing of the break is retarded by the angle of cam rotation equivalent to the displacement between points 1 and 2.

Figure 11 shows the principle of contact adjustment and the setting of the heel. the 6-lobe cam shown at "C" holding the rocker "R" fully lifted with the heel "H" on the peak of the lobe determines the maximum height to which the upper contact is raised. As the cam cannot raise the rocker any higher than this maximum lift, the position of the heel depends on the fixed contact adjustment and its location relative to the spindle centre. Figure 11 shows the principle of construction generally used. A fixed contact is mounted on a contact plate "P" and movable about the angle (a). The adjustment of the contact plate determines the fully-open gap "OG" between contacts and this is the means by which the adjustment is made.

The shape and width of the rocker heel is very important. This is illustrated in Figure 12 where two lobes are assumed to be moving in the direction of the arrows. The edge of the heel "HP" at "TE" is just leaving the lobe face and the contacts are closing. When the cam is moved through distance "D" the rising face of lobe L2 meets the edge of LE, raises the heel and rocker and separates the contacts. The distance (d) is therefore comprised of "D" plus the width of the heel. The period of closed contacts "D" will therefore be affected by any change in the width of the heel even though the lift of the rocker is unaltered. Wear and rounding-off of the leading and trailing edges may alter the heel width making it narrower and increasing "D"; an over-wide heel will similarly shorten "D".

CONTACT DWELL (CAM ANGLE).

The period of contact closure "D" in Figure 12 is the time during which current flows in the primary winding of the ignition coil and builds up a magnetic field preparatory to the breaking of the points, the collapse of this magnetic field and the generation of high voltage in the coil secondary winding. This is such an extremely important factor in engine performance that a special instrument has been designed to measure the period in terms of the number of degrees during which the distributor cam rotates while the contacts are closed. This is called the dwell angle or cam angle.

Figure 12 shows the cam angles of a 4-lobe single-rocker assembly for a 4-cylinder engine. The cam is shown with the rocker heel mid-way between the lobes. The contact dwell or cam angle - i.e., the period during which the points are closed - is shown by the shaded area "O". The period during which the points remain open is unshaded. The cam angle is the period "D" in degrees, illustrated in linear form in Figure 12. The phase angle "P" in a four-cylinder distributor is 90° and is the angle of cam rotation being one contact opening point "OP1" and the next in sequence "OP2".

Any alteration in the fully open adjustment of the breaker point gap changes the cam angle - in other words, by changing the contact gap the period of time during which the points remain closed and opened is altered. Adjusting the gap wider will cause the rocker heel to meet the cam lobe earlier in rotation and lower down the slope; this will result in later closing and earlier opening thus reducing the interval of dwell. Decreasing the gap will increase the interval of dwell.

FIG. 11.

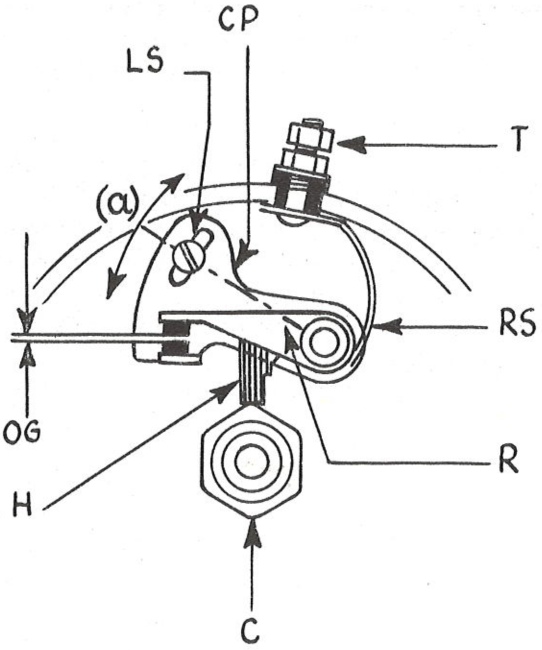
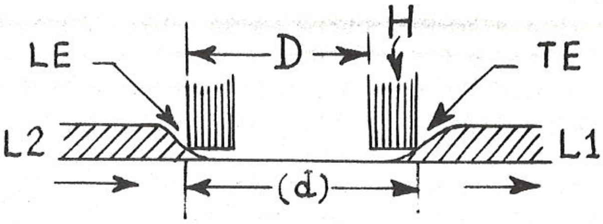

CP
LS
T
(α)
RS
OG
H
R
C

FIG. 12.


H
LE
D
TE
L2
L1
(d)

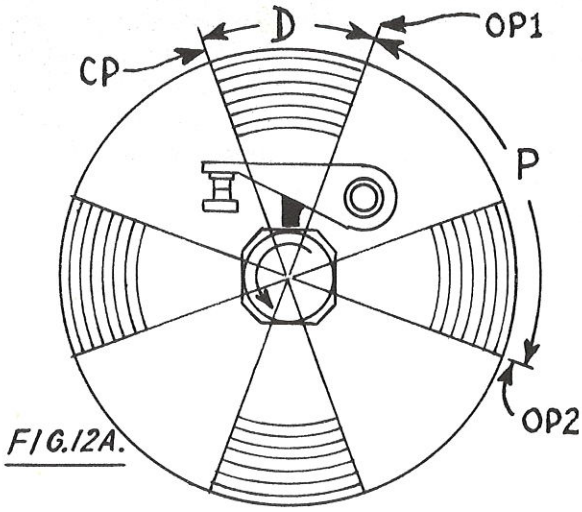
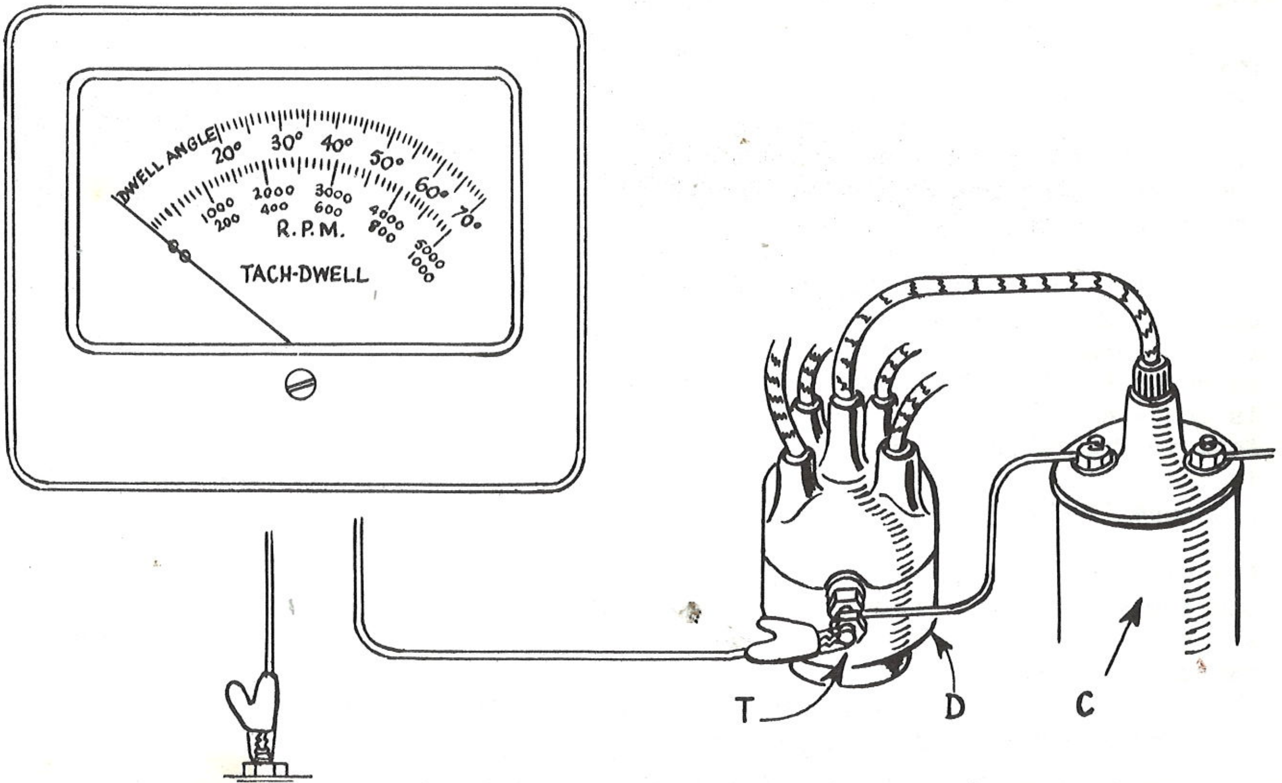

D
OP1
CP
P
OP2

FIG. 12A.

FIG. 13.


DWELL ANGLE
20°
30°
40°
50°
60°
70°
1000
200
2000
400
3000
600
4000
800
5000
1000
R.P.M.
TACH-DWELL
T
D
C

Therefore a larger reading of cam angle than normal indicates that the gap is too narrow and a lower reading of cam angle than normal indicates that the gap is too wide.

A narrow dwell angle has the effect of reducing the output of the coil at high speeds because the closed contact period is too short to enable a full magnetic field to build up and consequently full high voltage to be generated. A wide dwell angle results in over saturation of the coil at low speeds and has the effect of burning or pitting of the points because the condenser is unable to absorb the extra energy in the coil windings.

Accurate setting of the contact breaker points is specified by distributor manufacturers in terms of a fully-open gap. This ensures that the rate of the lift is correct as the rocker heel meets the cam face at a proper angle. A measurement of cam angle confirms the cam form and verifies that other mechanical factors are correct. This is due to the fact that the dwell angle is disturbed by any change in the rocker heel width and the cam profile as a result of wear even if the gap is satisfactory.

CONTACT POINT ADJUSTMENT AND CAM ANGLE.

The distributor contact point spacing should be set accurately with a feeler gauge or dial indicator. After adjusting the gap to the manufacturer's specification the cam angle should be measured with the Crypton Tach-Dwell Tester which gives a direct reading of the cam angle in degrees of distributor rotation. If the cam angle is outside the correct limits - after the contact points have been adjusted - it may indicate that the rocker arm is bent or is of the incorrect type or the breaker plate is faulty.

It has been the practice in the past to set the breaker points by adjusting the gap to a specified cam angle as read on the Tach-Dwell Tester. Because of certain unavoidable manufacturing variations this has sometimes resulted in too little point opening causing ignition trouble.

Cam angle is vitally important to secure good ignition at high speeds because the points must close long enough to allow a full magnetic field to be built up in the ignition coil - or the coil to "saturate" during each interval of point closure. The point opening - as already explained - changes the cam angle - if the points are widened the cam angle is reduced and if the points are narrowed the cam angle is increased.

The actual point opening is important at starting and low speed operation. If the points are set too close arcing and burning of the points may occur which will cause hard starting and poor low speed operation. In view of the importance of cam angle to secure good high speed performance and a point opening to secure good starting and low speed operation it is in practice necessary to check both when dealing with the distributor.

The point opening should be adjusted first in accordance with the manufacturer's instructions and a measurement then made of the cam angle. A tolerance is given in the cam angle figures issued by manufacturers; this allows for differences between units in manufacture and it is adequate if the measured cam angle is within plus or minus figures given in manufacturer's data.

MEASURING CAM ANGLE.

The Crypton Tach-Dwell Tester is specially designed for the accurate measurement of cam angle. It also measures the engine r.p.m.

The instrument and its methods of connection is shown in Figure 13. A switch on the Tester sets the instrument to measure engine r.p.m. and also to measure the cam angle on 4, 6 and 8 cylinder engines. The first check is to measure the engine r.p.m. and for the purpose of making the test a speed of 1,000 r.p.m. is desirable. By adjusting the switch to the cam angle test position according to the number of cylinders in the engine, the instrument will then give a direct reading of the cam angle. This can be compared with the manufacturer's figures.

A test is then made at an engine speed of 2,000 r.p.m. when the cam angle should be within 3° of the previous reading. If there is a greater variation than 3° it indicates a worn spindle or bushes, bent or damaged spindle, worn cam or loose base plate. The distributor must then be removed for reconditioning or replacement.

POINT OPENING AND IGNITION TIMING.

A change in the point opening changes the cam angle and -a change in the cam angle changes ignition timing. There is an alteration of 1° in the crankshaft timing for each degree of change in the cam angle setting. If, for example, a distributor designed for a cam angle of 45° actually has a cam angle of 49° the latter figure will mean a change of 4° in each closed-contact period and this will mean that the engine is timed late, after the angle has been adjusted and the ignition timing is not re-adjusted. It is, therefore, always necessary to retime the distributor when the contact gap is adjusted. It is also important that the cam angle is correct before setting ignition timing.

SPARK TIMING.

To obtain maximum power from an engine the compressed mixture must develop its maximum pressure just when the piston is about to commence its downward stroke. Since there is a time lag in burning the mixture the spark must take place before the piston reaches top dead centre on its compression stroke.

When an engine is idling the spark occurs just ahead of top dead centre. In some engines a timing mark is made on the flywheel at a point that number of degrees before top dead centre at which the spark should be adjusted for maximum power, acceleration and economy. Timing adjustment can be made with a Timing Light which makes the mark appear stationary with the engine running and shows its position relative to a fixed point.

As the engine speed increases the spark must take place earlier to ensure maximum pressure when the piston is about to descend on its power stroke. Means must therefore be provided to vary the spark automatically in accordance with engine speed. This is provided by an automatic timing mechamism built into the distributor.

CENTRIFUGAL ADVANCE.

As the engine speed increases, the time available for the mixture to ignite and burn, and to develop its maximum pressure becomes increasingly shorter. To get maximum power from the compressed mixture at increasing engine speeds the ignition system must be so designed that the spark takes place earlier. This is accomplished by the centrifugal advance mechanism built into the distributor.

The principle of this mechanism is shown in Figure 14 where "S" is the distributor spindle carrying a plate "AP" and a spindle extension "SE' fitted with a cam sleeve "SC" which carries a cam "C" and a cross piece "CP" with two pegs. As shown in Figure 15 a pair of flyweight assemblies is carried on the plate; the whole assembly rotates in the direction "R".

As the speed increases, the flyweights fling outwards against the tension of springs as shown in Figure 16. The toggles move the sleeve assembly forward in direction of rotation. The angle of displacement "AA" between the two assemblies causes the cam lobes to lift the rockers in advance of the idle position by the same number of degrees.

The amount of advance at various engine speeds is carefully determined by the engine and distributor manufacturers and represents an extremely critical adjustment. An engine will only operate at maximum efficiency throughout its full speed range when the automatic advance characteristics of the distributor are strictly correct.

It is therefore essential to make a test of the automatic advance characteristics of the distributor. The most effective method of doing this is to remove the distributor and test it on a Distributor Test Bench where the exact advance in degrees at all operating speeds is shown on a special synchroscope displaying a neon firing pattern which travels over a calibrated scale and gives a direct reading of the actual advance in degrees.

VACUUM ADVANCE.

Owing to the wide variations of load with speed the spark advance needed for maximum engine efficiency is not proportional to speed. When accelerating or on steep hills the advance is not the same as on level ground. To provide for this condition and to establish ideal advance characteristics, an additional form of vacuum controlled automatic advance mechanism is used on many distributors.

At part throttle the vacuum in the intake manifold is high and, as a result, less air and fuel enter the cylinder. Also, the mixture is less highly compressed. Mixtures at lower compression burn more slowly and therefore to get maximum power the ignition must take place earlier in the cycle. Consequently, additional spark advance beyond that provided by speed alone will increase fuel economy.

This is achieved by using the engine vacuum to advance ignition additional to the speed advance.

The vacuum advance unit has a spring loaded diaphragm "D" which is linked to the distributor plate "RB" or housing as shown in Figure 17. When the engine is idling no advance is required. The closed throttle "T" cuts off the vacuum supply to the unit. As soon as the throttle is opened the inflow of the gas "F" has a venturi effect and a depression in the chamber "VC" in Figure 17 enables external air pressure "AP" to force the diaphragm and spring inwards pulling the rocker around in the direction "RA" moving the rocker assembly towards the advance cam lobes, and enabling the cam to close and open the points earlier in the cycle. The breaker base is centred on ball bearings "B". This gives a spark advance based on vacuum in the intake manifold. As the compression varies in the cylinder the spark advance also varies, giving a greater engine efficiency.

At given engine speeds a certain advance obtained by the centrifugal mechanism plus additional possible advance due to vacuum is provided. For example, the

FIG.14.

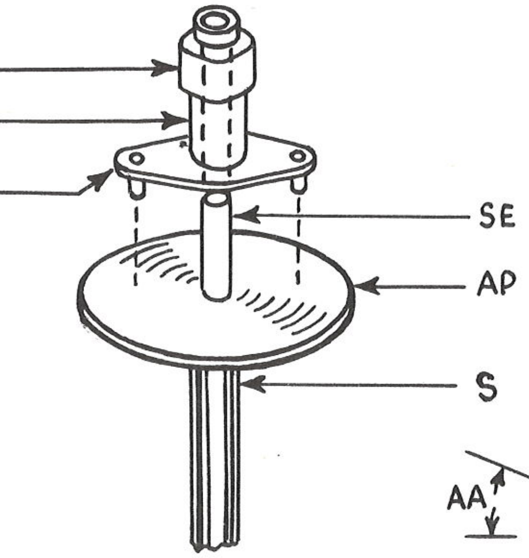

C
CS
CP
SE
AP
S

FIG.15.

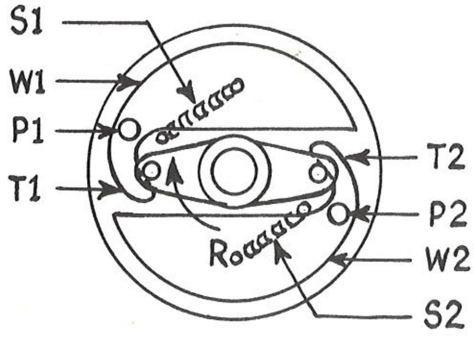

S1
W1
P1
T1
T2
P2
R
W2
S2

FIG.16.

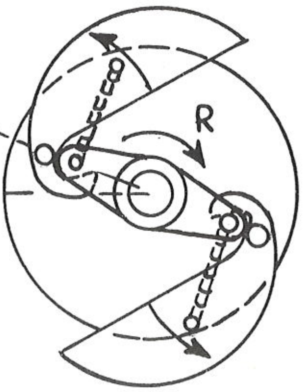
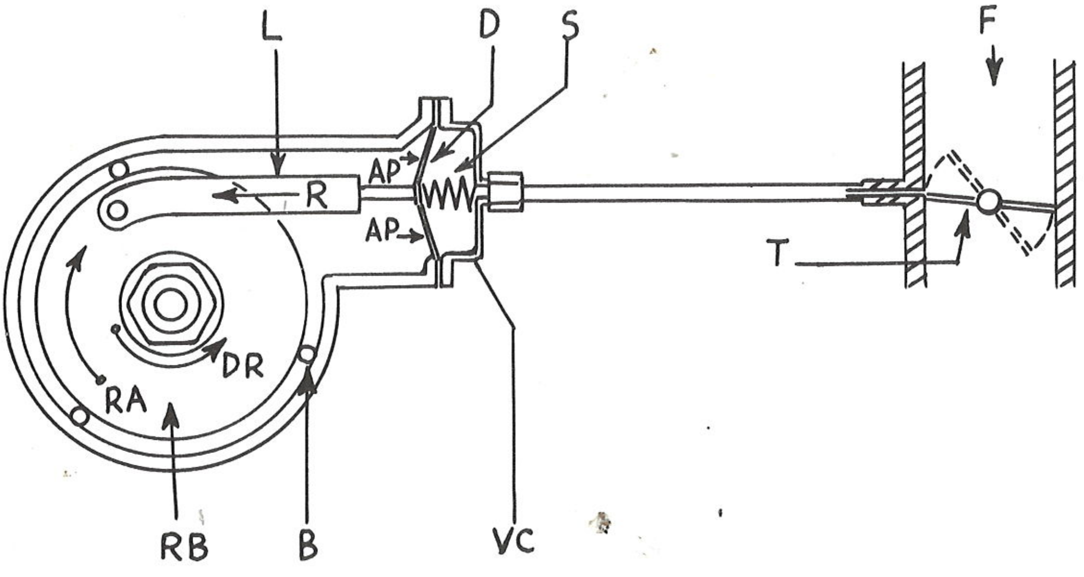


FIG.17.


L
D
S
F
AP
R
AP
T
DR
RA
RB
B
VC

centrifugal advance at a given speed may be say 12 degrees. If the throttle is only partly opened an additional vacuum advance of another 12 degrees may be given, making a total of 24 degrees. If the throttle is wide open there is no appreciable vacuum in the intake manifold and consequently no vacuum advance and the automatic advance is determined by speed only.

Vacuum advance is strictly an economy device and ensures that increased fuel economy will be obtained when the car is properly driven. If, however, the owner drives with a wide open throttle whether the car is in low or high gear, the economy due to vacuum advance will not be gained.

DISTRIBUTOR INSPECTION AND TEST.

Efficient distributor operation is vital to good engine performance. In many instances the distributor does not receive the attention it requires. This prejudices the quality of service and impairs the results in final engine performance.

The distributor is so important that it should be checked, removed and tested on a Distributor Test Bench every 5,000 miles. The following tests are required:

(1) Cam Timing - the number of degrees between distributor breaks.
(2) Breaker Contact Resistance - the condition of the contacts.
(3) Breaker Arm Spring Tension.
(4) Cam Angle.
(5) Worn Cams.
(6) Bent of worn distributor shafts.
(7) Centrifugal advance mechanism.
(8) Vacuum advance mechanism.
(9) Synchronising double breaker distributors.

Before removing the distributor for testing on a Distributor Test Bench the position of the rotor in the distributor housing and also the position of the housing in the engine should be carefully marked. The engine should not be cranked or the car moved in gear after the distributor is removed, otherwise the position of the distributor rotor will be altered when the distributor is refitted, making ignition timing more difficult.

SERVICING DISTRIBUTOR BREAKER POINTS.

There are two factors which need to be considered in the servicing of breaker points. Firstly to check and see whether the points are clean and making good contact and secondly whether the point opening is correct so that the points remain closed and open for the correct interval of time. It is a simple matter to test the breaker points for cleanliness. All that is needed is to connect a suitable voltmeter across the points, close them and measure the voltage drop. If the points are making good contact there will be no appreciable drop - it should not be higher in any case than 1/10th volt.

The breaker point setting should be checked with a feeler gauge and a direct test then made of the closed period in degrees with a Tach-Dwell Tester.

If, when making the voltage drop test the voltage is higher than 1/10th volt, the points should be cleaned before further tests are made; if the dwell angle reading is outside the manufacturer's specified figures, then an adjustment should be made before proceeding further. A test should always be made with a Tach-Dwell Tester to determine the mechanical condition of the distributor. As already stated the reading at a speed of

2,000 r.p.m. should be within 3 degrees of the 1,000 r.p.m. reading. This means that if the cam angle reading is say 38 degrees on a 6-cylinder engine at an idling speed, then the reading should be within 3 degrees of this when the speed is increased to 2,000 r.p.m.

A visual inspection of distributor breaker points will tell the experienced mechanic a good deal about ignition condition. It is particularly important to make certain that the point alignment is correct.

It may be found when inspecting the points that they have a rough surface. This does not necessarily mean, however, that the points are worn out. Any roughness between the points will match so that an adequate contact area is maintained. Distributor breaker points will continue to give satisfactory service until most of the tungstan is worn away. If it is found that the points are burned or have become pitted there is always a reason. It is not necessarily a cure to fit new points because if the cause of burning or pitting remains uncorrected then the trouble will only recur. The main reasons for point burning or pitting are as follows:

(1) HIGH PRIMARY VOLTAGE. If the voltage of the points is too high it will cause point burning. This can result from an improperly adjusted voltage regulator or a regulator which is inoperative. It will also be caused by incorrect adjustment of the third brush on third brush generators.

(2) POINT GAP TOO NARROW. If the setting of the breaker points is too close the cam angle will be too large and the points will remain closed for too long a period of the total operating time. This will increase the average current flow through the points and cause them to burn rapidly. It is, therefore, important to make sure that the point setting is correct.

(3) HIGH CONDENSER SERIES RESISTANCE. If the series resistance of the condenser is too high it will prevent the condenser operating normally and result in point burning.

(4) OVER OILING OF DISTRIBUTOR. This will produce a deposit on the points and cause rapid burning. The trouble is usually easy to detect because the oil produces a smudgy line under the points.

(5) IMPROPER CONDENSER CAPACITY. If the condenser is over or under capacity it will cause a transfer of tungstan from one point to the other. A "hill" will be formed on one point and a "valley" on the other. If the "hill" is on the positive point it indicates that the condenser is under capacity and if the "hill" is on the negative point, then the condenser is over capacity.

DISTRIBUTOR MAINTENANCE.

The principal requirements in distributor maintenance are as follows:-

(1) Distributor Cap ... inspect the distributor cap for cracks, carbon runners and burning and check the H.T. terminal sockets for corrosion. Also check segments for excessive burning.

(2) Distributor Rotor ... inspect the rotor for cracks and see that the contact strip is tight. The edge of the rotor contact burns with use and if the burning is excessive a replacement is needed.

(3) Contact Points ... contacts which are only greyish in colour and only slightly burned are satisfactory for continued good service. If they are badly pitted they should be replaced. Dirty contacts can be cleaned with a few strokes of a fine cut distributor contact file. Emery cloth or sandpaper should not be used because particles may become embedded and cause burning. The points should not be filed completely smooth but merely cleaned.

(4) Aligning Points ... to align the contact points close the contacts and carefully inspect making sure that there is full contact over the whole face area. Align the contact points by bending the stationary contact - do not bend the breaker arm.

(5) Contact Point Gap ... the contact point gap must be correct to ensure good point life and because of its effect on good cam angle. To check the gap turn the driving shaft until the rocker heel is on a high point of the cam. Then check the gap with a correct wire feeler gauge between the contacts. Adjust the points by loosening the stationary contact screw and retighten. A feeler gauge should not be used on rough contacts as the gauge will only measure the distance from the high spot to high spot on the points and not the actual opening.

(6) Contact Spring Tension ... Spring tension is important because too high a spring pressure will cause excessive wear of the cam and the heel and too little spring tension will cause bouncing which will result in missing at high speeds. A spring testing gauge will give an accurate test of spring pressure by attaching the hook of the gauge under the rocker just behind the contact and pulling on a line perpendicular to the contact face. The reading must be taken just as the contacts separate.

INSTALLING DISTRIBUTORS.

When installing the distributor on an engine, the following points need to be carefully noted:

(1) Turn the rotor to the same relative position in the distributor housing as with the original unit.

(2) Make sure that the housing and rotor are in the same position as previously.

(3) Make a proper job of the distributor mounting and pay particular attention to earthing.

(4) If the advance mechanism of the distributor was found to be defective, verify that there are no worn timing gears or oil bump because these may have been primarily responsible for the trouble and - if not corrected - the trouble will recur.

(5) Carefully retime the distributor to the engine.

IGNITION TIMING.

A Vacuum Gauge and Tach-Dwell Tester can be used for the setting of ignition timing for maximum engine power or - a Timing Light can be used to adjust the setting of the timing according to the vehicle manufacturers' specifications.

Consideration must also be given to the type of fuel used. With modern high octane fuels better performance and more power and economy can generally be obtained with ignition timing advanced slightly ahead of the manufacturer's settings but still within the limits generally recommended.

If the engine has excessive carbon or if a lower grade of fuel is used it may be necessary to retard the spark below the standard setting in order to eliminate pinking. It should, however, be appreciated that under this condition the performance and economy of the engine will be below par and the cause of the pinking should therefore, wherever possible, be corrected. When pinking is experienced the most usual causes are:-

(1) The improper operation of the distributor automatic advance or vacuum control.

(2) Spark plugs of incorrect heat range.

(3) Faulty spark plugs.

(4) Deficient spark plug gaskets.

(5) Improperly adjusted valve tappets.

(6) Lean carburettor mixture.

(7) Air leaks in the carburettor.

(8) Excessive carbon in the cylinder head.

(9) A choked cooling system resulting in high engine temperatures.

(10) A low grade of petrol.

PRACTICAL CONSIDERATIONS RE IGNITION TIMING.

Ignition timing is such an important matter that its importance cannot be over-emphasised. It has a very big effect on engine performance and economy. In the majority of cases it is possible to obtain a material improvement in engine performance merely by the correct adjustment of ignition timing for maximum power. If no other adjustment than ignition timing is carried out on an engine its performance will often be materially improved.

In modern engines it is necessary to time the ignition within an extremely fine tolerance as close as plus or minus 1/10,000th of a second.

When the compressed mixture in the cylinder is fired by the spark at the spark plugs the mixture does not instantaneously explode. What happens is that a flame starts at the plug and radiates in all directions in the combustion chamber until its travel is limited by the walls of the combustion chamber and the pistons. The mixture does not explode - IT BURNS.

Although the rate of flame travel is very rapid a certain amount of time is actually taken. For best engine performance it is essential to ensure that the burning of the mixture is completed and that maximum pressure is developed when the piston is in the right position to receive the maximum pressure. Since a certain amount of time is needed to burn the mixture and develop maximum pressure on the completion of the burning, it is as already stated, necessary to start the spark ahead of the time when the combustion will be completed. From a practical point of view this is not easy because there are many outside influences which vary the speed of combustion and which are beyond normal control. These include:

(1) The compression pressures developed which depend upon throttle opening and engine speed, the mechanical condition of the engine and atmospheric pressure.

(2) The time required for combustion which is influenced by the amount of carbon in the combustion chamber, the water jacket temperatures, the temperature of the air and the burning rate of the air-fuel mixture.

(3) The mixture conditions, i.e., the air-fuel ratio.

It might seem from the foregoing that it is almost impossible to time an engine properly and it is true to say that a large proportion of engines on the road are not properly timed. Even where the timing is correctly adjusted in accordance with the data issued by the car manufacturer there is no assurance that this timing is correct for the actual operating conditions of the engine because of the many variables as already described.

There is, however, a practical way in which an engine can be timed and which takes account of these variables and this is to time the engine for maximum power - this can be called POWER TIMING. What is done is to adjust the ignition timing until the engine develops maximum power as shown by the highest vacuum reading which can be obtained on a Vacuum Gauge or a maximum r.p.m. reading which can be obtained on a Tach-Dwell Tester. The ignition timing is adjusted until the maximum engine power is obtained and - after all this is the only result that matters. All the unknown factors which influence spark timing will have been compensated for.

Ignition timing is, however, only correct at the speed of throttle opening at which the adjustment is made. Assuming for example that an engine is timed at 1,000 r.p.m. open throttle and the engine speed is then increased to say 2,000 r.p.m., it will be found that the power of the engine can be improved by advancing the time beyond the original. The reason for this is that the speed of combustion remains substantially the same but at higher speeds the crankshaft travels through more degrees of rotation during the time required for the completion of combustion. Therefore, by the time the combustion is completed the crankshaft is beyond the point of maximum power position. The pistons will be lower down in the cylinder and not in the correct position to gain maximum benefit from the pressure developed by combustion. This is the reason why it is necessary to time earlier and to advance the timing as the engine speed increases.

The correct timing point required to reach power through the medium of centrifugal advance and throughout the entire engine speed range is established at the factory and the centrifugal advance mechanism of the distributor is then designed so that it automatically follows the series of timing points established. A line is drawn through these points and is called the centrifugal advance curve. In order to advance or retard the timing the distributor assembly is rotated. This does not, however, change the centrifugal advance curve because all the timing points throughout the speed range are being advanced or retarded. If the ignition timing is advanced the complete curve is moved upwards; if retarded the curve is lowered. This means that if the centrifugal advance curve is satisfactory and basic timing is set correctly for one speed, then the timing will be correct for all speeds.

It is often found in service that the centrifugal advance mechanism is not operating in accordance with factory standards. It may advance too slowly or too fast with increase of speed. In order to make a reliable check of this the best method is as already instanced, to remove the distributor and test it on a Distributor Analyser which shows the spark advance in degrees throughout the entire speed range. By comparing a performance curve of the actual advance characteristics obtained from testing with the manufacturer's data any faulty condition can be verified.

Experience has shown that ignition timing requires more frequent adjustment than anything else on the engine. Because of the many variables which affect ignition timing it is the subject of a great deal of trouble. It is important, therefore, to pay special attention both to the ignition timing as carried out with a Vacuum Gauge and Tach-Dwell Tester and also to an accurate test of the distributor automatic advance characteristics. For best results a road test is desirable after ignition-timing has been adjusted to eliminate any possible complaint of pinking that may develop under load conditions. Where a chassis dynamometer is available, the road test is, of course, unnecessary

THE CAUSES OF DETONATION AND PRE-IGNITION.

When ignition timing is adjusted with the use of a Vacuum Gauge, the procedure is to advance ignition until the highest vacuum reading is obtained and the needle is just about to drop. In some cases if the vehicle is sent out with this ignition timing a detonation or pinking may occur and in order to correct for this it is usual to retard ignition by approximately half inch reading of the Vacuum Gauge.

As already mentioned, there are many variables which affect ignition timing and of these the most important variable is fuel. To appreciate this it is necessary to consider the question of fuel in more detail.

All grades of fuel have what is called an OCTANE RATING. This rating indicates the ability of the fuel to resist detonation - or knocking - or pinking. To determine the octane number of any fuel a test is made in an engine under load on a Dynamometer. A test fuel is used which consists of two special types of fuel. One of these is called ISO-OCTANE which resists knocking and the other is called HEPTANE which knocks very easily. The test is so devised that the fuel being tested is compared to a blend of Iso-Octane and Heptane. When the blend of Octane and Heptane exactly duplicates the tendency to knock on the fuel being tested then this fuel is said to have an octane number equal to the percentage of octane used in the reference fuel. For example, if it takes a blend of 70% octane and 30% heptane by volume to make a fuel that has the same characteristics as the fuel being tested, then the test fuel is said to have a 70 octane rating. The higher the octane rating the better the fuel as far as its resistance to knocking or detonation is concerned.

When the compressed mixture in the combustion is fired it burns by a flame which starts at the plugs and radiates in all directions until it is stopped by the cylinder walls and pistons. As the compressed mixture burns it expands and this causes the pressure which forces the piston down on its power stroke. As the mixture burns and expands it compresses the unburned portion of the fuel tighter and tighter. If the remaining portion of the fuel is compressed beyond a certain point (which depends on its octane number) it will explode and release its energy instantaneously.

Carbon accumulation has an effect on detonation because carbon insulates the heat transfer to the water jacket and as the carbon builds up the mixture gets hotter and detonation easily develops. This is why decarbonising an engine will often reduce a tendency to detonation previously experienced.

Detonation is also influenced by timing. When the spark is retarded detonation is reduced. The reason for this is that when the spark is retarded the first portion of the fuel starts burning later in relation to crankshaft rotation. Before the last portion of the mixture can be compressed tight enough to explode the piston has moved down the cylinder and reduced the pressure. This reduces knocking but - the power and economy of the engine are greatly reduced.

Pre-Ignition.

Pre-ignition is caused by combustion taking place before spark ignition. It starts the mixture burning too early in exactly the same way as would be done by an early spark setting. The piston is still moving upward on its compression stroke and is not ready to begin the power stroke.

Pre-ignition is usually caused by something which is running too hot in the combustion chamber. This may be protruding cylinder head gaskets, sharp edges of carbon or hot spark plugs. In other words "hot spots" exist in the combustion chamber which starts the fuel burning in the same way as the spark at the plug gap.

The diagnosis of pre-ignition requires that a load is placed on the engine. The pre-ignited cylinder can then be easily diagnosed because the spark plug on the cylinder is shorted out but the engine will keep on running as well as it does with the plug firing.

Pre-ignition may be due to early spark timing or to poor fuel which heats up the combustion chamber to such an extent that pre-ignition takes place. Therefore, when faced with a complaint of pre-ignition it is necessary to ensure that a suitable grade of fuel is used.

A frequent cause of pre-ignition is hot spark plugs. This can be often diagnosed by inspecting the plugs. If the plugs have a white chalky appearance this is an indication that they are running too hot.

When checking for pre-ignition the following points should be considered:-

(1) See that the spark is not advanced beyond peak power.

(2) Check that the fuel is of adequate octane rating.

(3) See that the spark plugs are not too hot.

(4) Check that the air-fuel ratio is not unduly lean because if it is overheating will occur and this may cause pre-ignition.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 6

FUEL SUPPLY AND CARBURETTION

A Practical Explanation of
Modern Carburettion Systems

CRYPTON EQUIPMENT LIMITED
BRIDGWATER – SOMERSET – ENGLAND

FUEL SUPPLY AND CARBURETTION

A practical knowledge of the basic principles of fuel pumps and carburettors is essential for the satisfactory testing and diagnosis of engine performance troubles and the tuning of engines for maximum power, acceleration and economy.

This lesson covers the fundamental operating principles of modern fuel supply and carburettion systems and will enable the service man to make the essential tests needed to verify when the carburettion division is efficient, to locate normal causes of trouble and carry out those adjustments which are within the scope of normal shop servicing procedure.

THE FUEL SYSTEM.

The fuel system of every automobile engine consists of the tank for storing the fuel, the fuel pump for pumping the fuel to the carburettor and the carburettor for mixing the proper proportion of petrol and air, together with connecting pipe lines and filters etc.

TWO MAIN SECTIONS.

There are two main sections in the complete fuel system, each of which has a definite duty to perform.

One is the fuel delivery section which is concerned with raising liquid fuel from the tank and delivering it to the float bowl of the carburettor in a quantity proportional to the engine requirements.

The other is the vaporising and admixture section in which the fuel is drawn off through a series of jets in the form of a fine spray and carried into the induction manifold of the engine by the ingoing air stream. The mixture of air and petrol produced by the carburettor is carried into the engine cylinders by external atmospheric pressure because of the lower pressure or "vacuum" in the cylinders.

The proportion of air and fuel mixed by the carburettor is referred to as the "air-fuel" ratio (abbreviated to "AFR") and this ratio must be accurately controlled to ensure good engine performance.

MAINTENANCE OF FUEL LEVEL.

The central exchange unit which links the fuel delivery and vaporising and delivery sections of the complete fuel system is the carburettor float bowl. This serves as a reservoir to feed the carburettor jets at the varying rate required according to engine speed and power. The necessary reservoir of fuel must be maintained in the carburettor float bowl but must not exceed the correct level.

Fig.1 illustrates the principle of controlling fuel level in the carburettor float bowl. Fuel enters at the inflow pipe "IF", passes through a filter "FR" and the

FIG.1.

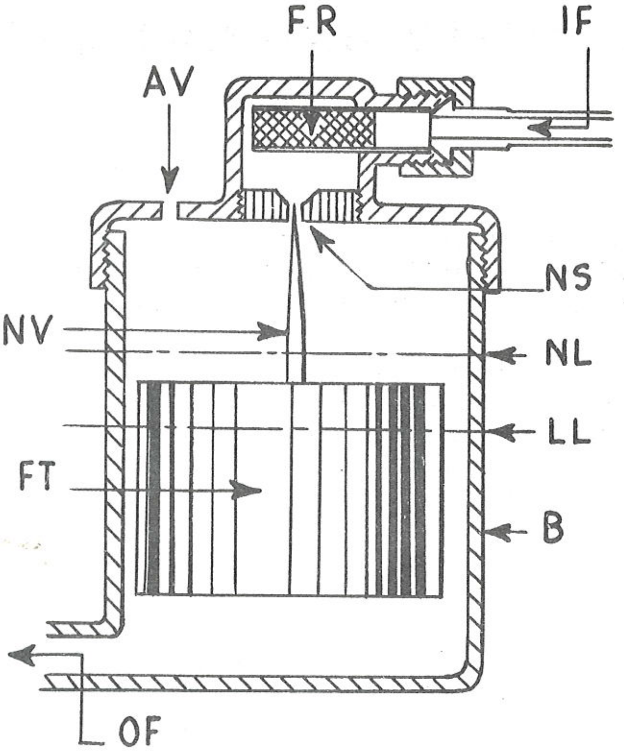
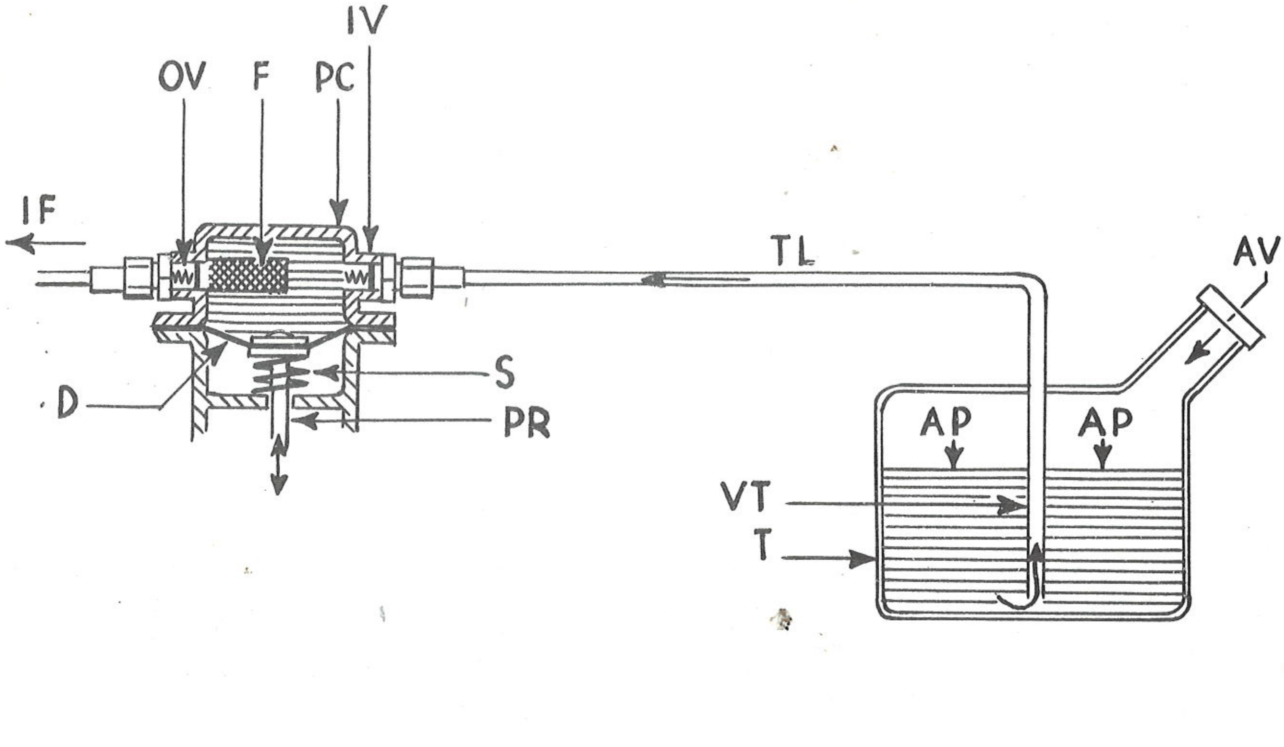

FR
IF
AV
NS
NV
NL
LL
FT
B
OF

FIG.2.


IV
OV
F
PC
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TL
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S
D
PR
AP
AP
VT
T

orifice of a needle seating "NS" into the bowl "B". As the bowl fills up, the float "FT" rises and the needle valve "NV" is pushed up by the float until it enters and closes the seating "NS". In the illustration fuel would still be flowing in with the level at "LL" but, when it reaches the higher level at "NL" the pressure of the valve in its seating will shut off the flow. The level "NL" therefore is the controlled fuel level at which the inflow of fuel is cut off.

Fuel leaves the bowl at the orifice "OF" being drawn off by the jets. This allows the level of fuel to fall and decreases the float pressure on the valve, allowing more fuel to enter to restore the level.

The air vent "AV" serves the dual purpose of permitting the escape of air as fuel flows into the bowl, and also enables atmospheric pressure to expel fuel into the jets as is described in more detail later.

DELIVERY PRESSURE AND CAPACITY.

The delivery system must supply fuel at a stated pressure and the maximum volume of delivery must be adequate for the full power consumption rate of the engine. When no faulty conditions exist, the type of diaphram pump used on all modern engines satisfactorily fulfils these functions. Delivery pressure is determined by the diaphram spring and delivery capacity by the maximum stroke or the deflection of the diaphram. Both pressure and capacity must be tested when diagnosing an engine and the results compared with the manufacturer's data for the vehicle concerned.

Fig.2 illustrates the principle of operation of the delivery system. The pump chamber "PC" is filled with fuel, the flexible diaphram "D" is drawn downwards by the pull rod "PR" compressing the spring "S". When the pull rod is released the spring exerts pressure on the diaphram. This compresses the fuel and forces it out through the filter "F" and the output valve "OV" into the pipeline "IF" which leads to the carburettor float bowl. The flow of fuel continues until the diaphram reaches the top of its stroke. Then - when motion is reversed and the pull rod is again drawn down - the pressure falls to zero and a partial vacuum is created in the chamber as the diaphram flexes downwards and "creates space" in a similar manner to the pistons of the engine on their induction phases. The air pressure "AP" on the surface of the fuel in the tank "T" causes fuel to flow up the vertical tube "VT" into the tank line "TL", entering the pump chamber via the inlet valve "IV", thereby replenishing the fuel delivered.

The pumping action of the fuel pump may be operated by mechanical linkage with the engine or by an electro-magnetic solenoid and in both cases the fuel is delivered in a series of waves or pulses. In the case of a mechanically-actuated pump, delivery commences when the engine is cranked and continues while it is running. In the case of an electrically-actuated pump, the pump starts to operate when ignition is switched on and will fill the float bowl before the starter is operated. In both cases, the delivery pressure exerted by the spring is balanced by the pressure of the needle valve on its seating when the float is raised to the correct fuel level in the carburettor bowl. The delivery pipeline is thereby closed and the spring is not able to expel fuel from the pump until the fuel level falls to open the needle valve again and permit resumption of flow. When this happens the spring remains compressed. Electrical action is suspended but mechanical action continues to operate idly while exerting no pull on the pull rod "PR".

VACUUM BOOSTER PUMP.

Certain types of fuel pumps - particularly for U.S.A. vehicles - are fitted with a vacuum section which acts as a booster to the intake manifold vacuum to provide uniform operation of vacuum-operated windscreen wipers at all engine speeds and loads.

The movement of a rocker arm through the vacuum diaphram link pushes the vacuum diaphram upwards and into the air chamber against the pressure of the diaphram spring. The pressure created in the air chamber by the upward movement of the diaphram keeps the inlet valve closed and expels air through the outlet valve into the engine manifold. The return stroke releases the compressed diaphram spring and the spring pressure is then sufficient to push the diaphram down which creates a vacuum in the air chamber. This vacuum causes the outlet valve to close and air is drawn through the inlet valve from the windscreen wiper.

The diaphram operates only when the engine vacuum is not sufficient for windscreen wiper action. When the engine manifold vacuum is higher than the vacuum created by the pump, the stronger engine vacuum pulls the diaphram into the air chamber and holds the vacuum link out of engagement with the rocker arm which consequently does not move. The windscreen wiper then operates on the normal engine vacuum without any assistance from the vacuum booster pump. When the engine manifold vacuum is low as occurs on acceleration or at high engine speeds, the boost vacuum created by the pump ensures proper operation of the vacuum operated windscreen wiper.

TESTING THE FUEL PUMP.

The fuel pump has a direct bearing on the efficiency of the carburettor and should always be tested when checking engine performance. There are two tests which need to be made.

(1) A test for pressure.
(2) A test for capacity.

Testing Fuel Pump Pressure.

The first operation is to measure the pressure of the fuel pump for the following reasons:-

(1) If the fuel pump pressure is too low, the engine will be starved of fuel at high speeds.

(2) If the fuel pump pressure is too high, this will result in an unduly rich mixture and may in extreme cases, cause flooding of the carburettor. A rich mixture is one of the main causes of poor engine performance and excessive petrol consumption.

To test fuel pump pressure a suitable pressure gauge as illustrated in Fig.3 is used. This gauge gives readings of pressures up to 5 lbs. per sq. inch on the upper scale or up to 3.5 grams per sq. millimetre on the lower scale.

To make the test, the delivery pipe is detached at the pump outlet union, the union removed and one of a set of screw adaptors fitted in its place. This adaptor forms a convenient means of attaching a special "T" pipe which is used for both pressure and capacity tests.

Fig.4 shows how the "T" pipe is fitted and indicates the attachment of a hose "H" to the "T" junction and to the nozzle "N" of the fuel pump test gauge. The joints must be firm and leak-proof and the screw cap "S" firmly screwed on.

When the pump is operated, the diaphram spring pressure of the pump tends to force fuel out into the "T" adaptor and the hose line to the gauge. These flow paths are, however, sealed off, so the volume of air within the hose line etc. acts as a buffer and is compressed to the same pressure as the diaphram spring pressure.

The gauge indicates this pressure which in the case of both types of pumps should be between $\frac{3}{4}$ to 2 lbs. per sq. inch. The exact pressure for each type of pump is specified in the manufacturer's service data.

Where the pump is of the mechanical drive type, it may be operated by using the starter or running the engine slowly on the fuel remaining in the float bowl.

An electrical pump will pulse only when the ignition is switched on and the engine need not be started; the pulsing of the pump will cease when a sufficient pressure has been built up to suspend the pump action.

Careful observation of the pressure gauge will show clearly when faulty conditions exist. The readings should climb with a series of cumulative increases until a steady maximum pressure is reached, after which no further increase will be shown. Full pressure should be gained within three or four strokes or pulses.

When a greater number of pulses is required to achieve full pressure and the reading increases in small steps, this indicates a possibility of leaking valves, diaphram or gaskets. This will be confirmed if there is a low maximum pressure and if the reading declines over a period of ten to fifteen seconds. A serviceable pump should hold its maximum pressure without operating for this period - any leakage will cause the reading to fall steadily and will prove that fuel is leaking back into the lower pressure areas in one or more of three directions, namely :-

(a) It may be escaping to the outer air past the diaphram seal.

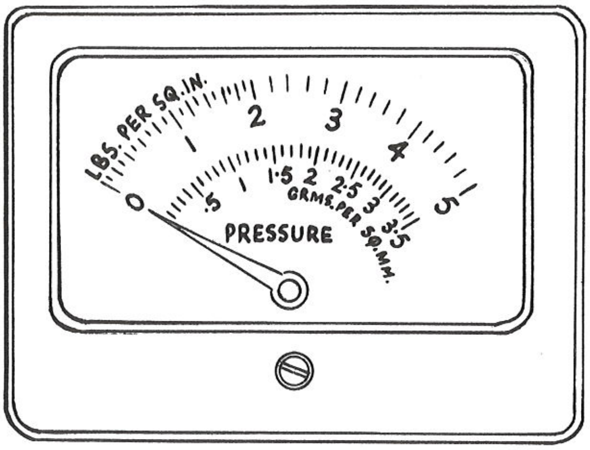
(b) It may be seeping back into the tank pipeline through a faulty inlet valve.

(c) Fuel may be escaping through a porous faulty diaphram. This is the most serious condition and it may be possible to see petrol dripping from the underside of the pump or - it may be finding its way into the crank case, causing oil dilution which if not corrected will rapidly cause bearing failure in the engine and lead to an expensive repair job.

A standard type of fuel pump when properly fitted will not exceed its designed pressure. If the gauge reading rises above the limit established by the manufacturers and given in their service data, the reason will be found in the use of an incorrect spring or one which has been packed up with washers or the like. High pressure will also result if the magnitude of diaphram deflection has been increased by the ommission of packing or spacing between the pump and body and the crank case.

The result of high fuel pressure will appear in heavy consumption of fuel and possible carburettor flooding due to the fuel level being raised above normal. The pressure on

FIG. 3.


LBS. PER SQ. IN.
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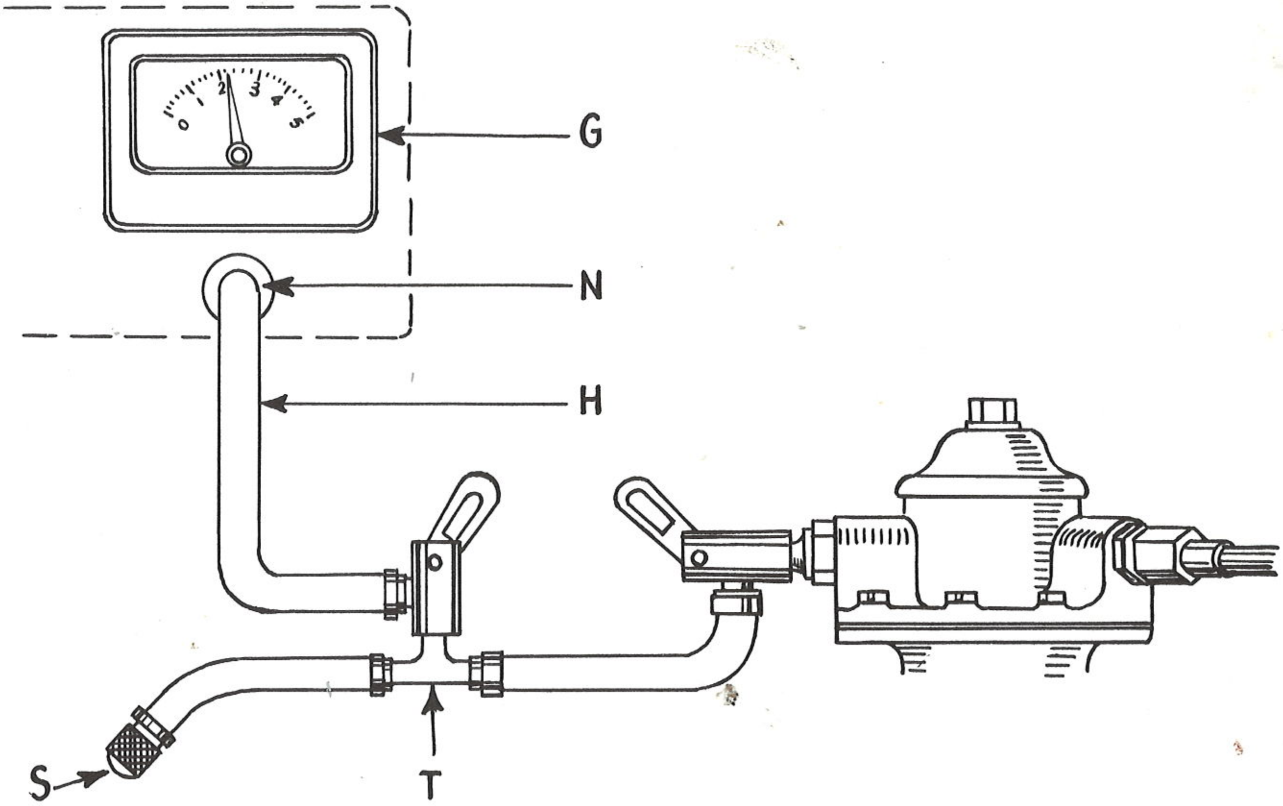
GRMS. PER SQ. M.M.
PRESSURE

FIG. 4.


0
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G
N
H
S
T

the float valve is governed by the buoyance of the float. Whilst this pressure will be sufficient to control the inflow by closing the valve at the correct level, abnormal pressure causes fuel to leak past the needle valve, its pressure overcoming the resistance of the valve.

Careful testing and the fitting of genuine replacements and the correct servicing of the fuel system will obviate the faults as indicated above and fully corrective treatment must always be recommended when the test results show the fuel pump pressure to be either below or above the manufacturer's established limits.

TESTING VACUUM BOOSTER PUMP.

If the vacuum booster pump diaphram is punctured, this will often result in excessive oil consumption, misfiring or rough running. If the windscreen wiper operates satisfactorily on engine vacuum but not on pump vacuum, this indicates that the vacuum pump is inoperative. To test the booster pump attach a vacuum gauge to the port connected to the windscreen wiper motor with the outlet pipe disconnected. The test must always be made with the outlet open. With the engine operating at approximately 2,000 R.P.M. the gauge should show from 7 to 12 inches of vacuum. If the vacuum is less than 7 inches it indicates that the booster pump is inoperative.

TESTING FUEL PUMP CAPACITY.

To test the fuel pump capacity, a graduated container holding up to ¾ pint (1 litre) is required. The screwcap "S" in Fig.4 is removed and the pump operated by running the engine at idling speed for 30 seconds. The engine should be stopped promptly at the end of 30 seconds when - with an average type of pump - the container should be full.

Failure to deliver the necessary quantity of fuel will result in ultimate failure of engine performance through fuel starvation. This may be due to wear in the pump actuating linkage, causing short-stroking, choked filters, partial obstruction of the tank pipeline, leaking valves or faulty diaphram.

When making tests of fuel pump capacity, care must be taken to avoid spilling any of the fuel. The adaptors and hose connection must be firmly attached. If air can leak out under pressure while making pressure tests, petrol will enter the hose line causing spillage and falsifying the test results.

When the test connections and adaptors are removed, the delivery pipe to the float bowl should be checked for blockage or internal perishing. Filters, float, needle valve and the inside of the bowl for possible sediment deposit, should also be carefully inspected.

THE PURPOSE OF THE CARBURETTOR.

The carburettor has three important functions to fulfil - as follows:-

(1) It must measure within high limits of accuracy the proportions of air and petrol required to meet the varying speed and load conditions of the engine.

(2) It must produce a mixture of the correct air and fuel so that the mixture will burn efficiently in the engine.

(3) It must thoroughly atomise the fuel leaving the nozzle and distribute it evenly throughout the air stream delivered to the engine intake manifold.

In order properly to perform these functions and to ensure that the engine will develop its maximum power at lowest fuel consumption, modern carburettors have several independent systems which come into effect according to the demand of the engine. These systems are as follows:-

(1) The Float System which controls the fuel level in the carburettor (and which we have already briefly discussed).

(2) The Idle System which controls the fuel when the throttle is closed and at light load speeds up to about 20 miles an hour, and for the partial control of the fuel supply for light load speeds up to about 30 miles an hour.

(3) The High Speed System which controls the flow of fuel during intermediate or part throttle operation; this system usually starts at about 20 miles an hour and continues up to the speed obtained with wide open throttle.

(4) The Accelerating System which supplies a rich mixture for rapid acceleration.

(5) The Choke System which provides a rich mixture for starting a cold engine.

THE FLOAT SYSTEM.

We have already dealt with the float system which controls the fuel level in the carburettor float bowl to maintain a constant level so that fuel does not leak out of the nozzle when the engine is not operating. The float level depth must be maintained and must be in strict accordance with the manufacturer's specifications.

Remember that too little fuel pump pressure will cause the engine to starve for fuel at high speed. Too high fuel pump pressure will result in a rich mixture or flooding.

THE VENTURI PRINCIPLE.

Before considering the other systems, it is important to acquire a proper understanding of the importance of the "Venturi" principle used in the carburettor.

Fig.5 illustrates how this operates. The ingoing air stream "AS" passes through a tube of reduced bore known as a choke tube, as indicated at "C". The surface is shaped to ensure a smooth flow and the speed of the air flow increases in proportion to the narrowing of the bore. At the narrowest part where the speed is greatest, a jet tube "JT" projects into the air stream. The open end of the jet tube is turned into the stream at "JA" and the effect of the air stream is to create a partial vacuum in the vicinity of this aperture. Consequently, external air pressure "AP" on the surface of the fuel in the float bowl "FB" forces fuel up the tube via the calibrated jet "J" and discharges it in the form of a spray or "fog" into the main air stream. The jet "J" has a small hole which limits the quantity of fuel passing and the size of this hole determines the air-to-fuel ratio.

The mixture of atomised fuel and air enters the manifold past the throttle valve "T" which controls the amount of mixture entering and also the rate of ingoing air flow.

VARIABLE RATIO EFFECT.

With a fixed throttle opening the rate of air flow in volume will be directly proportional to piston speed and therefore to R.P.M. This is illustrated in the upper diagram in Fig.6. The venturi vacuum effect does not, however, vary in the same direct proportion but increases in an ascending curve as illustrated in the lower part of Fig.6.

The result of this in practice is that the air-fuel ratio changes with the rate of air-flow. At low speeds a small proportion of fuel enters the stream and as speed increases the percentage of fuel rises. This means that with a simple venturi jet of the kind we have described, there would be a lean mixture at idling but this would become increasingly rich with higher engine speeds. This tendency for a simple venturi to supply an increasingly rich mixture with a higher air flow must be cancelled out to ensure the correct proportion of air and fuel under all conditions.

COLD STARTING FUEL SUPPLY.

The efficiency of combustion is at its lowest when the engine is being started from cold. Under this condition the engine itself is cold, the oil is heavy, and the added load of the starter on the battery tends to weaken the ignition spark. Low piston speed during starting and idling reduces the speed of air through the choke and the vacuum at the main jet is not sufficient to draw fuel in the required quantity for good starting.

Most carburettor designers use an auxiliary starting system which by-passes the main jet and choke and provides a starting mixture of correct proportions.

Fig.7 shows the principle of a commonly used method. The throttle "T" is nearly closed so that a comparatively high induction vacuum is created. The main air flow "MA" passes through the choke at low speed until it is drawn through the narrow space between the throttle plate and the bore at "MP" where the speed of passage is increased and a partial vacuum created in the side passage opening on to the narrow space. Air enters the vertical tube at "A", picks up a fuel spray from the starting jet "SJ" and carries this down past the adjusting needle valve "AN" to join the main air stream entering the carburettor.

We have in effect a miniature carburettor system which supplies a rich mixture in the form of a bubbly emulsion, the quantity of which can be adjusted by the needle valve "AN" entering the main air stream in which it is atomised and diluted to form a fuel gas of correct proportions for quick starting. The quantity of fuel supplied through this auxiliary system is sufficient for idling speeds and the air fuel ratio of the incoming mixture can be adjusted by turning the screw of the needle valve, thereby regulating the proportion of emulsion entering the main stream.

FIG. 5.

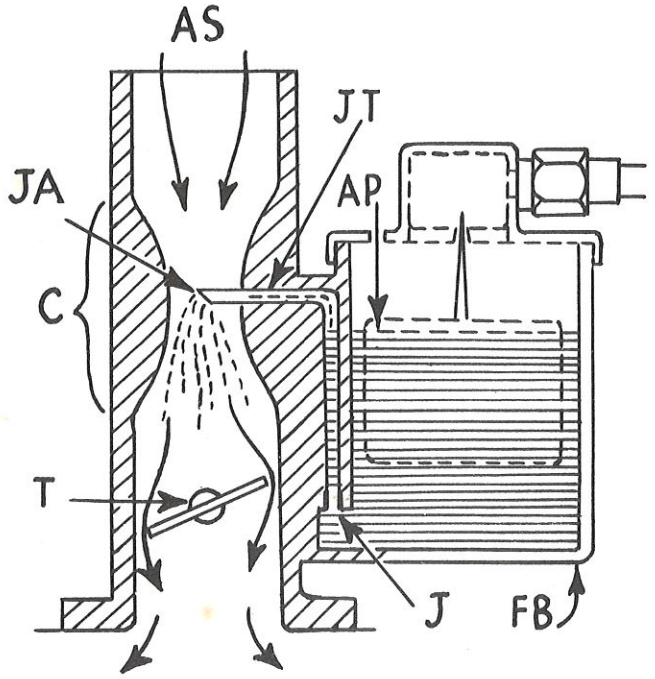

AS
JT
JA
AP
C
T
J
FB

FIG. 6.

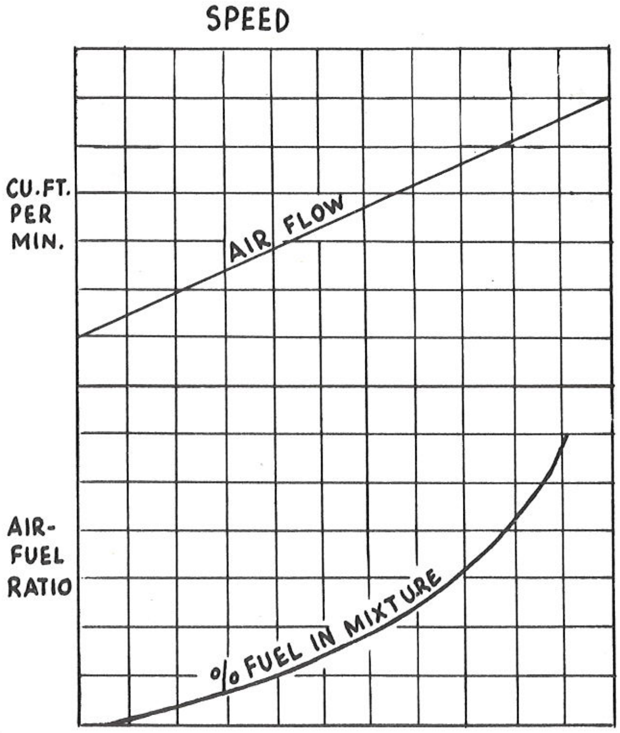


FIG. 7.

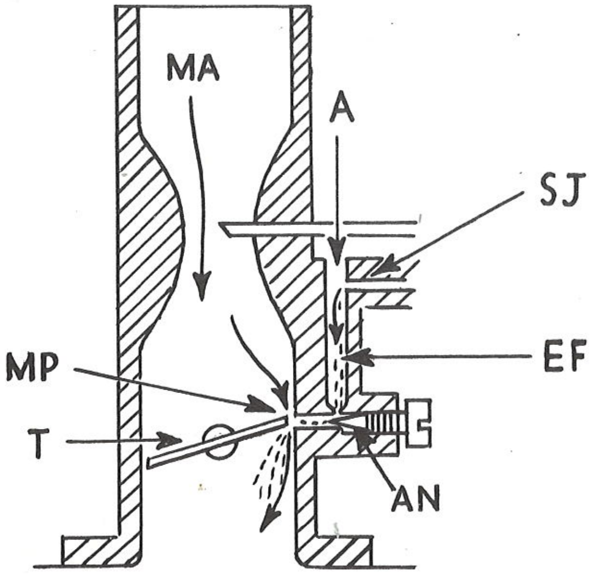
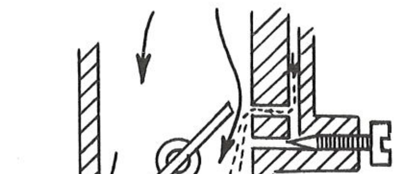

MA
A
SJ
EF
MP
T
AN

FIG. 8.



"FLAT SPOT" COMPENSATION.

All service men will be familiar with the symptom known as "flat spot" which occurs when the throttle is opened suddenly from the idling position. The engine falters momentarily and will sometimes "spit back" until it begins to speed up.

This is due to the collapse of vacuum as the space between the throttle plate and the chamber wall widens. The emulsion flow ceases but the air stream through the air speed through the main choke is not high enough to collect an adequate supply from the main jet. The mixture becomes weak until speed rises sufficiently to bring in the main jet system.

In some carburettors a second side passage is located above the idling passage at a point where rapid air flow is still maintained as the throttle is opened. This admits a rich mixture to "tide over" until the main air flow has speeded up and avoids the weak mixture interval which is the cause of "flat spot". Fig.8 illustrates this principle of design.

MAIN JET COMPENSATION.

Several methods are in use for the purpose of regulating the main mixture. We will consider one well known system - the "Zenith" air-well compensating device, the principle of which is illustrated in Fig.9.

The main air stream "MA" passes through the choke "C" and creates a partial vacuum at the jet "JO" so that external air pressure on the fuel surface in the carburettor bowl forces fuel through the compensating jet "CJ" and the passage to the main jet.

The quantity of fuel is restricted by the size of the jet "CJ" and the air pressure on the surface of fuel in the air well "AW" forces this fuel into the main stream to supplement the restricted flow. When the vacuum at "JO" increases with main air flow, the well is drained out and air bubbles begin to enter the limited flow from the compensating jet.

This means in effect that as the main air flow speed increases, causing the mixture normally to become richer, this tendency is cancelled out by gradual aeration of the fuel supply and a consequent weakening effect. When a carburettor of this type is correctly balanced, the air fuel ratio will remain virtually constant over the whole range of air speed through the throat section as the compensating system continuously corrects the enrichening tendency of the simple venturi.

ACCELERATION MIXTURE CORRECTION.

In the same way as a "flat spot" can occur between idling and the main-jet take-over point, so can a similar position arise when the throttle is opened wide at low air speeds. Compensation must be provided to prevent this by supplying a rich mixture momentarily.

This is supplied in some cases by means of an "acceleration pump" actuated by the throttle. This pump injects a charge of fuel into the main air stream to provide the necessary enrichment correction until the increased engine speed and air flow enables the main jet system to supply the required air-fuel ratio. It is not appropriate in

FIG. 9.

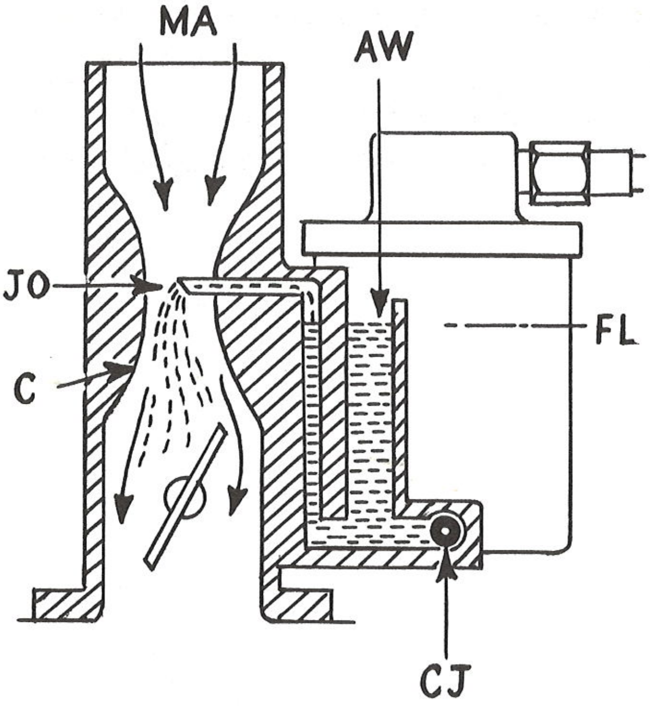

MA
AW
JO
FL
C
CJ

FIG. 10.

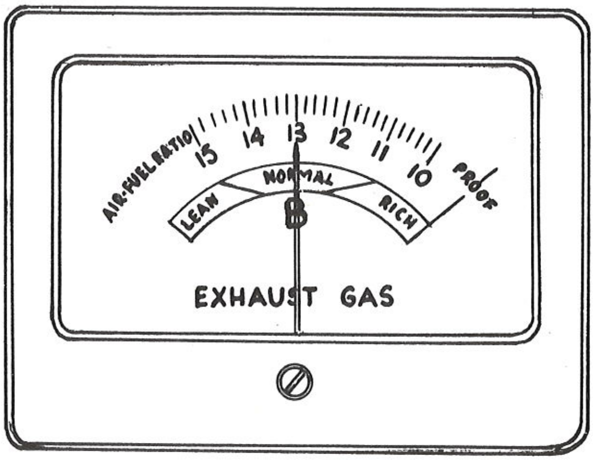
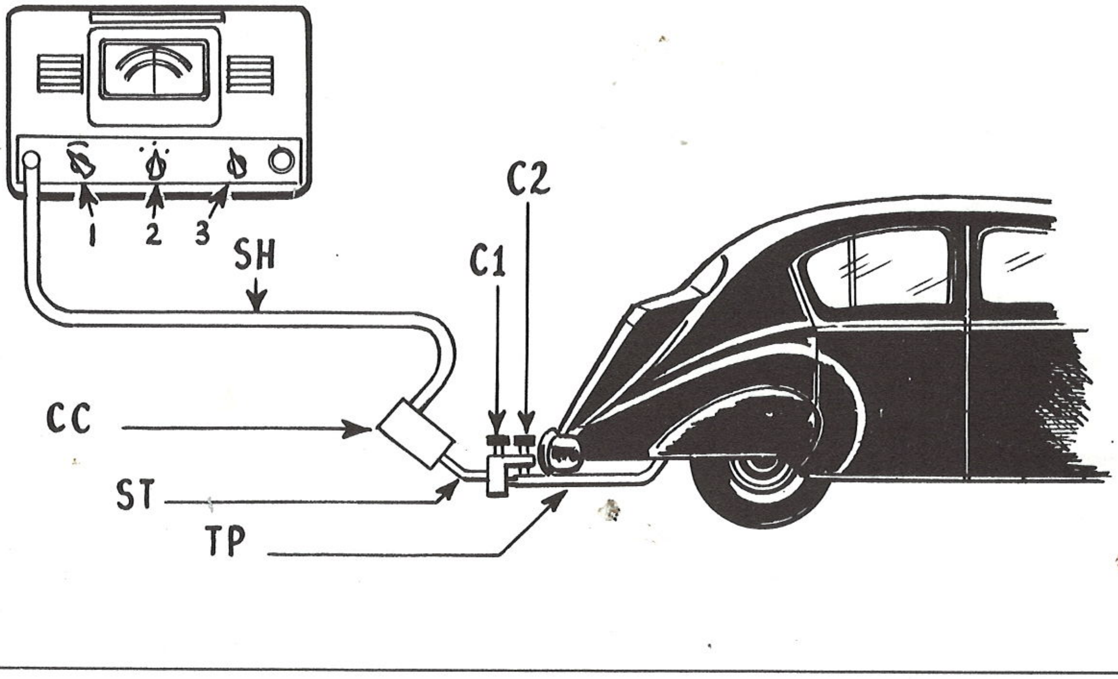

AIR-FUEL RATIO
15
14
13
12
11
10
PROOF
NORMAL
LEAN
RICH
B
EXHAUST GAS

FIG. 11.


C2
C1
1
2
3
SH
CC
ST
TP

the course of this lesson to describe in detail all the various carburettion systems in use or to dwell at length on the service data issued by the manufacturers. All operators should study information of various types of carburettors given in the manufacturer's service data or in workshop manuals dealing in detail with the subject of carburettion.

A SUMMARY.

(1) The Float System of the carburettor controls the fuel level in the carburettor to maintain a constant level to prevent fuel leaking from the nozzle and to provide an adequate basis for efficient carburettion.

(2) The Idle System controls the fuel at low or idle speeds up to approximately 30 miles per hour. Carburettor manufacturers use several methods to ensure that as engine speed is increased the mixture is progressively lean to the point of best economy.

The setting of "idle" adjustments on carburettors is an important service operation. The engine operates for long periods of time on the low speed system, with vehicles used for town driving this can be from 30 per cent. to 50 per cent. of the total running time, and during this period the carburettion is controlled by the idle adjustment. Actually the term "idle adjustment" is misleading because it indicates that the adjustment merely controls the mixture whilst the engine is idling. Actually, however, the adjustment controls the mixture at all times the car is running below about 30 miles an hour and during periods of deceleration, stopping, slowing down in traffic, etc.

(3) The High Speed System automatically controls the fuel, from about 20 miles an hour up to a speed of wide open throttle.

(4) The Accelerating System. Carburettors fitted with accelerating pump systems supply a rich mixture for rapid acceleration.

(5) The Choke or Starting System. The purpose of this system is to enable the carburettor to deliver an extremely rich mixture which will ignite when the engine is started from cold.

MEASURING AIR-FUEL RATIO.

In the service testing of the carburettor our main concern is to ensure that the carburettor is delivering the correct proportion of air and fuel under all operating conditions. The all-important function of the carburettor is to supply a correctly balanced air and fuel mixture for all conditions of engine loading and speed.

It is not possible to measure directly the ratio of air and fuel in the mixture being delivered by the carburettor but a practical method of doing this is available by analysing the exhaust gas. We can also take advantage of the fact that the carburettor idling mixture can be corrected against the readings of an Electric Tachometer and Vacuum Gauge, the adjustment being set to attain the maximum engine R.P.M. and vacuum indications at a fixed low throttle opening.

The instrument used for indicating the ratio of air and fuel, by analysing the exhaust gas, is the Exhaust Gas Analyser which is connected by hose to the exhaust tailpipe. The reading is shown as the proportion of air to petrol, thus when the instrument reads 13 it means that 13 parts of air by weight are mixed with one part of petrol. The scale of the exhaust gas analyser is illustrated in Fig.10, calibrated to cover the limits of air-fuel ratio experienced in practice, i.e., from 10 : 1 to 15 : 1. Coloured zones are provided below the main scale to indicate the significance of the readings and show where readings are abnormally lean or are normal or abnormally rich.

In operation, a sample of the exhaust gas is taken from the tailpipe of the vehicle and after being cooled and dried in the attachment coupled to the tailpipe, is passed into the Exhaust Gas Analyser.

Fig.11 shows the sampler tube "ST" secured in the tailpipe "TP" by a lock screw "C2". The sampler tube is so fitted and secured by the screw "C1" that a condensing chamber "CC" is in the position shown with a flexible hose "FH" connecting the condenser chamber to the Tester. The small proportion of exhaust gas which enters the sampler tube is cooled in the condenser chamber, any mixture being condensed and escaping through a leak hole. After the exhaust gas sample has passed through the Exhaust Gas Analyser it is discharged through a small hole in the instrument case.

USING THE EXHAUST GAS ANALYSER.

Carburettor Idling Test.

To test the carburettor air-fuel ratio at idling a vacuum gauge is connected to the intake manifold and the engine should run until it reaches normal temperature. The speed of the engine should then be adjusted to approximately 500 R.P.M.

The Exhaust Gas Analyser is connected as illustrated in Fig.11 and the instrument adjusted in accordance with the instructions supplied with it.

With both the Vacuum Gauge and Exhaust Gas Analyser connected and the engine running at approximately 500 r.p.m. adjust the carburettor idle screw so that the vacuum gauge holds practically steady at a reading between 17 and 22 inches of vacuum. When adjusting the carburettor idle screw do not turn the screw beyond the manufacturer's specified limits. With the idle adjusting screw set within the manufacturer's specified limits and with a steady vacuum reading between 17 and 22 inches, the air fuel ratio should be within 11.5 to 13.0 to 1 air-fuel ratio. The average reading is about 12.75 lbs. of air to one pound of petrol.

The idle adjustment should be set primarily for the maximum vacuum and r.p.m. readings rather than by the readings of the Exhaust Gas Analyser. The reason is that the vacuum and r.p.m. readings are more sensitive at low speed. If the mixture is rich or lean the Analyser will show this by the direction of its reading and will also confirm that adjustment correction has been made by the extent to which the Exhaust Gas Analyser gives a normal reading and the vacuum and r.p.m. readings simultaneously improve.

For most economical operation the carburettor should be adjusted to get the maximum vacuum and engine r.p.m. at an air-fuel ratio as near as possible to 12.75 to 1, but within the manufacturer's specified range of adjustment and without undue rough running or stalling of the engine.

Testing the Accelerating Pump.

The Exhaust Gas Analyser will indicate the operation of a carburettor accelerating pump. This is done by running the engine at about 2,000 r.p.m., noting the air-fuel ratio at this speed and then quickly pressing the accelerator full down and rapidly releasing, observing the action of the exhaust analyser meter as this is done. The meter pointer should move towards the rich side of the scale immediately after acceleration. If the pointer does not move towards the rich side or if it moves towards the lean side, it shows that the accelerating pump is not operating correctly and that adjustments or repairs are needed.

Checking Carburettor Compensation Response.

When the throttle is opened to bring the main jet into action and the idling system ceases to operate, the readings of the Exhaust Gas Analyser become more informative. This is the stage at which the compensation device - of whatever kind may be used in the carburettor being tested - has to maintain close control over the air-fuel ratio. The Exhaust Gas Analyser will show any deviation from the proper balance and what stage this deviation occurs.

When the engine is accelerated the air-fuel ratio should become slightly richer because either the accelerating pump or the compensating jet allows extra fuel to enter the air stream during the accelerating period. As stated previously, the operation of an accelerator pump will be seen in the swing-over towards the rich side of the instrument scale. This response may not be seen for a few seconds because the change in the exhaust stream has to find its way through the metering chamber of the tester before the instrument will respond.

When the carburettor has a Zenith type of compensating jet, the acceleration factor is checked by increasing the engine speed to 1,500 r.p.m. and allowing this speed to continue for a few seconds. The instrument reading should move towards rich and then decline to about 11 to 12, then gradually returning to the normal ratio as the main jet compensation begins to take effect.

When the engine speed is increased to about 2,000 r.p.m. the compensation should produce a mixture slightly leaner than that at idling - a reading of about 12.5 to 14.5 is usual. No hard and fast rules, however, can be established because with some vehicles a slightly richer mixture may be shown at 2,000 r.p.m. than at idling. The best guide to follow is the average results obtained with cars of the same make and type.

For full accuracy in testing the carburettor high speed system it is necessary to operate the engine under load by driving the vehicle on the road or on a Dynamometer. The Crypton Exhaust Gas Analyser can be satisfactorily used for road tests, being fitted with its own dry battery so that no external power is needed. The reason why load tests are needed for accurate checking of the high speed system is because the throttle opening is much less for the same engine r.p.m. when the engine is operated without load than when it is propelling the vehicle.

Testing Two-and Three-Carburettor Engines.

In dealing with a vehicle having more than one carburettor it is necessary to remember that a lack of balance or other faulty conditions may exist in one or more units. To start with, all controls should be synchronised. The tie-bar between throttles should be uncoupled and each throttle fully closed. The tie-bar should then be re-coupled, seeing that no back-lash exists. The best idling stop position is then adjusted by setting the stop screw.

In dealing with dual S.U. carburettors having variable jet control linked by control rod, this coupling should be disconnected in addition to the throttle coupling. One throttle should then be closed down and the normal tests made on the remaining unit including adjustment of the main jet for correct idling mixture. Having corrected one unit this should now be closed down and the other carburettor treated in the same manner. When both carburettors have been adjusted to give equal response the linkage is carefully re-attached, making sure that both throttles and jet control operate in unison. Then - with the engine running on both units, a final trimming of adjustment can be made, guided by the instrument reading.

It is essential that any alteration should be uniform on all carburettors in order to preserve the accurately balanced relationship which is so essential to good performance.

CARBURETTOR SERVICE.

The correction of carburettion faults by means of adjustment is in general limited to the setting of the idling mixture and the slow running throttle stop. A lack of balance in the form of an over-rich or over-weak mixture at various points in the speed range which may be due to faulty compensation, can only be rectified by servicing the carburettor in strict accordance with the manufacturer's instructions. Having made a correct diagnosis by the use of the Vacuum Gauge, Tachometer and Exhaust Gas Analyser, it can be seen whether adjustments will correct the trouble or whether further service is needed.

There is no need to define the carburettor fault beyond a recommendation for carburettor reconditioning because a complete detailed inspection and overhaul of the carburettor will have to be carried out both to locate the specific cause of the trouble and to correct it.

When interpreting the results of carburettor tests, it is necessary to make sure that what appears to be a carburettor fault is not due to some relatively simple outside effect such as leaking gaskets, loose mountings, sticking drain valve, external mixture control, choke pull-cable or automatic heat valve not operating.

There is one final point which must be remembered. This is that the constituents of the exhaust gas are influenced by factors other than carburettion, and the exhaust gas analyser will show any irregularities due to these outside factors. For this reason it is important that the carburettor analysis is made only when other possible reasons for poor performance have been eliminated. It is particularly important that the ignition system is checked before a test of the carburettor is carried out, so that any possible ignition defects which influence the Exhaust Gas Analyser readings are first located.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 7

STARTERS AND STARTING CIRCUITS

What to Know About the Operation and Testing of Automobile Starters.

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

STARTERS

The use of engines of higher compression with a greater number of cylinders and with more engine driven auxiliaries imposes a greater load on the starter, especially in cold weather. The starting handle is now regarded as a purely emergency device and is being omitted from an increasing number of vehicles. Failure of the starter under these conditions can amount to a serious breakdown involving appreciable inconvenience and expense.

To ensure reliable starting under all normal conditions a regular inspection and checking of the starter motor and circuit is essential. This includes the battery, starter motor, switch, cables, connections, drive engagement and actuating devices such as solenoid circuits and any special latching or automatic control which may be incorporated.

Where complaints are received of difficult starting, it must be determined whether the starting system is in need of service or whether the engine has lost its good starting ability through defective ignition, lack of proper fuel mixture, loss of compression, etc.

NATURE OF THE STARTING LOAD.

Before studying the action of the starting system it will be helpful first to consider the duty the starter has to perform.

Fig.1 is a graph which shows the power exerted by the starter from the instant the switch is closed to the point where the engine starts, the curve also fairly represents the current in the starter circuit.

At point 1 in the curve the starter switch is closed and the power surges up until the starter pinion starts to revolve. The power then falls as the starter speeds up to the point of engagement with the flywheel ring-gear at point 2 in the curve. Meeting the dead-weight of the flywheel inertia, the starter speed will now drop to nearly zero and the power rises sharply until the flywheel inertia is overcome and the flywheel starts to turn, this is indicated at point 3 in the curve. As the starter and flywheel speeds increase, power falls until one piston is forced up on its compression stroke, this resistance slows down the starter speed until top dead centre is reached at point 4. The piston then starts to descend on what would be the power stroke (although the first cylinder seldom fires). The release of pressure helps rotation, causing the starter speed to rise and the power to fall. The same up and down surge occurs at the next compression phase, as shown in point 5 and at each succeeding compression until one cylinder fires. The flywheel then tends to over-run the pinion and, if the other cylinders fire in sequence, the engine starts, accelerates and flings the pinion out of mesh. The starter will now continue to spin at high speed until the switch is opened as shown at point 7 in the curve.

FIG. 1.

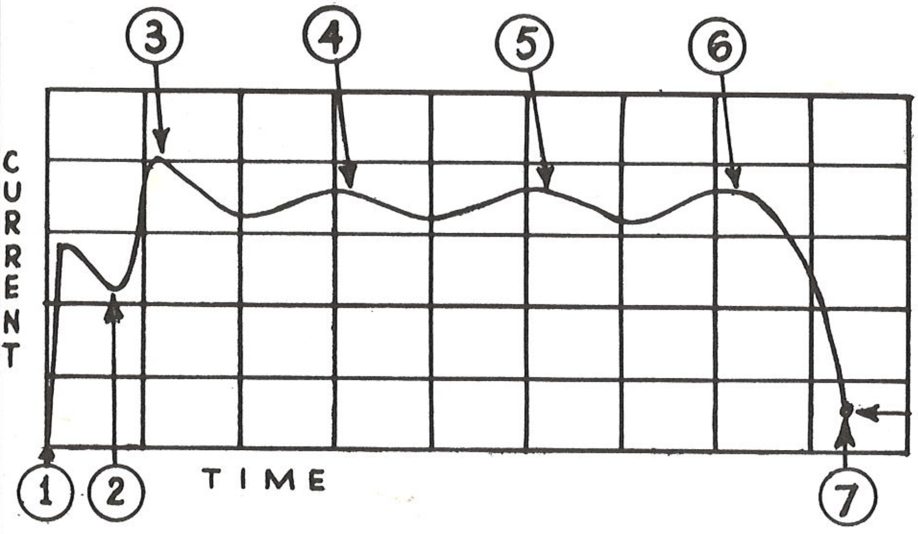


FIG. 2.

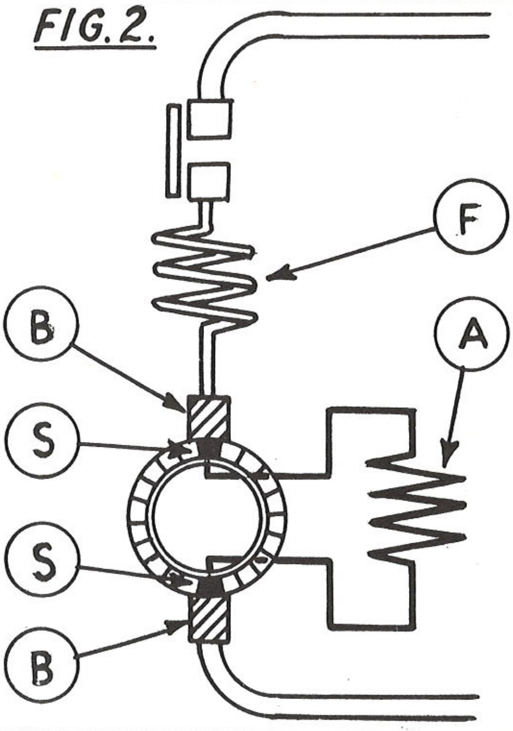


FIG. 3.

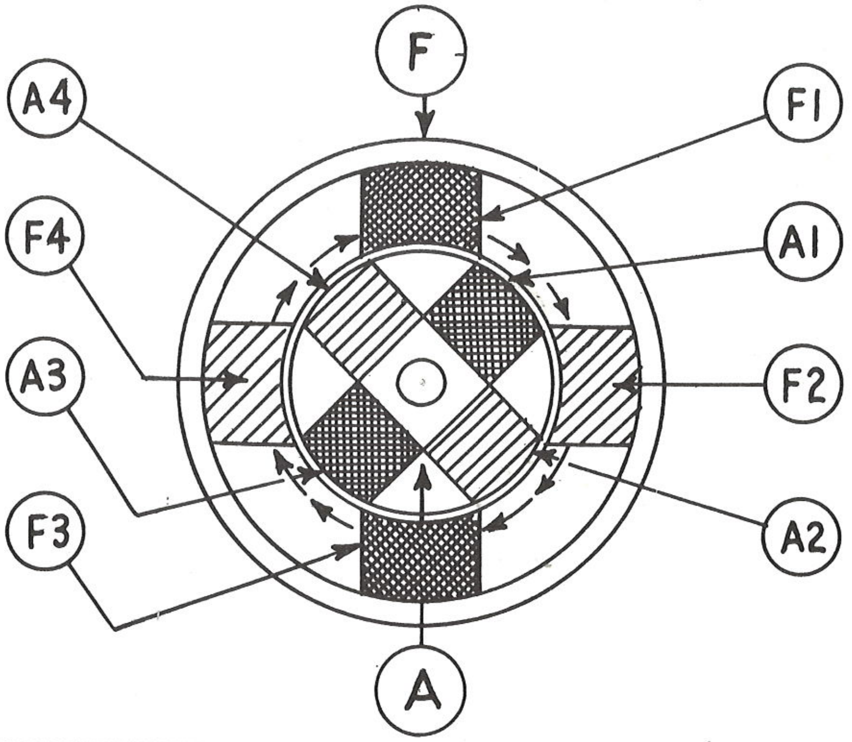
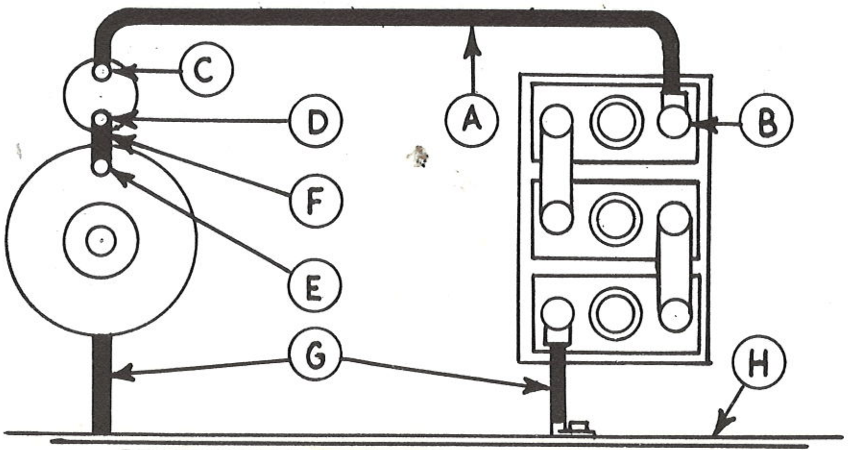

F
A4
F1
F4
A1
A3
F2
F3
A2
A

FIG. 4.



STARTING LOAD REQUIRED.

The amount of energy required to start the engine varies with a number of factors. The power consumption from the battery can, however, be assessed in terms of current and time or "Ampere/Seconds" i.e., the value of current in amperes and the number of seconds for which this current flows.

A cold stiff engine will require more power to start the engine crankshaft and pistons in motion, and will have to be rotated for a greater number of turns before the engine fires and starts running, than will be needed with the same engine when it is warm and free. Starting from low temperature imposes a greater load on the battery because of the higher internal resistance of the battery when it is cold, and there is added disability in producing a lively ignition spark because of the reduced battery voltage caused by the application of a greater current load by the starter.

These facts show why we must take account of existing conditions when starter performance is judged by engine load. A starter may readily start a warm and recently-switched-off engine, and we may easily assume that starting conditions are good. There is, however, no guarantee that the same starter will operate the same engine efficiently when the engine is cold and damp, and it is for this reason that we should make a proper inspection of the starter circuit whenever a complete diagnosis job is carried out.

HOW THE STARTER OPERATES.

The flow of current from the battery and the number of seconds for which this power flows provides an electrical input to the starter which is converted into mechanical energy which spins the shaft carrying the pinion at an increasing speed until the pinion engages the flywheel and then, when slowed down by the inertia of the engine, exerts a powerful turning effort or torque to get the engine started.

The manner in which the electrical input is converted into mechanical output is through the medium of magnetic force. The current flowing in the starter passes through the field coils fixed to the starter carcase shown at F in Fig.2, and also through the starter armature coils, shown at A. This flow of current sets up magnetic poles in the field coils and these magnetic poles are stationary because the field coils are fixed to the stationary starter carcase. The current flowing in the armature coils also sets up magnetic poles and the poles established by the stationary field coils will attract or repel the poles set up on the armature and will cause the armature to revolve. This effect is shown in Fig.3 which illustrates the stationary field poles at points F1, F2, F3 and F4 and the armature magnetic poles at points A1, A2, A3 and A4. The heavily shaded poles are of North (N) polarity and the light shaded poles are of South (S) polarity. Most of you know that unlike poles (N. and S.) are attracted together and "like" poles (N. and N. or S. and S.) are repelled apart. It is this that causes the armature to move in the direction indicated in the diagram. The magnetic poles produced on the armature are always at the same relative angles to the fixed field poles as brushes B connect commutator bars S in succession. (Fig.2). This means that the magnetic power is proportional to the current. This is a very important point to remember.

STARTER CURRENT.

The starter depends for its electrical efficiency on the following four factors:-

(1) The current in amperes at a given load.

(2) The number of turns in the starter fixed field coils.

(3) The number of turns in the armature moving coils.

(4) The angle of displacement between the magnetic poles.

The last three factors are determined by the design of the starter but the first factor, namely, the current in amperes taken from the battery, depends on a number of essential factors. From a servicing point of view it is essential to ensure that a sufficiently strong current flows in the starter windings to produce the strong magnetic forces required, and having produced this force, to see that it is not wasted through excessive friction or unduly heavy loading.

THE STARTER CIRCUIT.

A simple starter circuit is illustrated in Fig.4. This is the basis of all starter circuits. The complete circuit comprises a battery with a heavy cable from the live battery terminal "B" to the starter switch terminal "C". The starter switch is connected to the starter by the connection "D" to the starter motor terminal "E". This connection may be by a cable or strap "F" or the switch may be mounted directly on the starter end frame with no external connection. Both the starter and the battery are connected by cable or flexible straps to the vehicle chassis (Earth) indicated at "H". Assuming for the moment that the battery live terminal "B" is of positive polarity, the flow of current will be from battery terminal "B" to starter switch terminal "C", through the starter switch, thence through cable "F" to the starter terminal "D", through the starter and thence to the chassis via the Earth connection "G" and back to the battery negative terminal. If the battery live terminal is of negative polarity, the flow of current will be in the reverse direction, i.e., from the battery earthed terminal, through the vehicle chassis, thence to the starter by Earth connection "G", through the starter to terminal "E" and then through the starter switch and back to the battery negative terminal "B".

The cables connecting the battery to the starter and both the starter and battery to earth must be of adequate capacity to carry the heavy current which flows in the starter circuit and which may amount to several hundreds of amperes. The copper stranded wires in the cables or straps must be sufficient in number and size and all connections must be clean and tight. Both the fixed and moveable contacts of the switch must be in perfect condition and must make good contact when the switch is closed, and the starter itself must of course be in serviceable condition.

TESTING THE STARTER AND STARTER CIRCUIT.

The customer's complaints and diagnosis tests carried out on the vehicle will indicate the possibility of a definite fault in the starter or the starting circuit, sufficient to result in unsatisfactory starting such as slow cranking of a warm engine. For the reasons previously stated, it is desirable that starter tests should be made when the engine is cold, because this will result in faults being shown up more clearly. If we satisfy ourselves that starting is satisfactory when the engine is cold it is a certainty that operation will be satisfactory when the engine is warmed up.

In making starter tests we apply two stages of testing. One is to detect and locate any electrical losses which will rob the starter of a proper input of electrical power and the other is to identify any mechanical or electrical faults which may exist within the starter and which will prevent the full conversion of the electrical energy put into the starter into mechanical energy.

TEST THE BATTERY FIRST.

The battery is the starting point for all tests. No starting system will function correctly if the battery is unable to sustain the normal starter load. We have already described in Lesson No.2 how to carry out proper battery tests. If the battery is not substantially charged and healthy, then it must either be recharged to restore its normal charged condition, or be replaced by another battery known to be in good order.

CURRENT LEAKAGE CHECK.

First check the battery for possible current leakage. If any such leakage exists it will result in the battery becoming partly discharged overnight, despite the fact that the generator and charging system may be functioning satisfactorily.

To measure any possible leakage of current from the battery, remove the battery connections as shown in Fig.5 by disconnecting the battery earth cable clamp "BC" from the earth terminal "BT". Then clip the voltmeter test leads of the Crypton Volt-Ampere Tester to these two points as shown in the diagram. When connected in this way the voltmeter will show any small leakage of current which will be read as "Volts". What we are actually doing is to use the voltmeter as a milli-ammeter and to do this it is connected in series instead of parallel as is usual with normal voltmeter tests. If the voltage reading is within ½ volt, the leakage of current from the battery is within permissible limits. If the voltmeter reads higher than ½ volt, a test must be made to check the cource of current leakage. This may be due to bad insulation in the starter switch, or to defective insulation of the lighting and charging cable or the accessory sections of the electrical system.

When making the above tests, it is essential that all lamps and electrical load is switched off.

BATTERY VOLTAGE ON STARTER LOAD.

The next test is illustrated in Fig.6, where the voltmeter is connected across the battery terminals and the battery voltage read whilst the starter

FIG. 5.

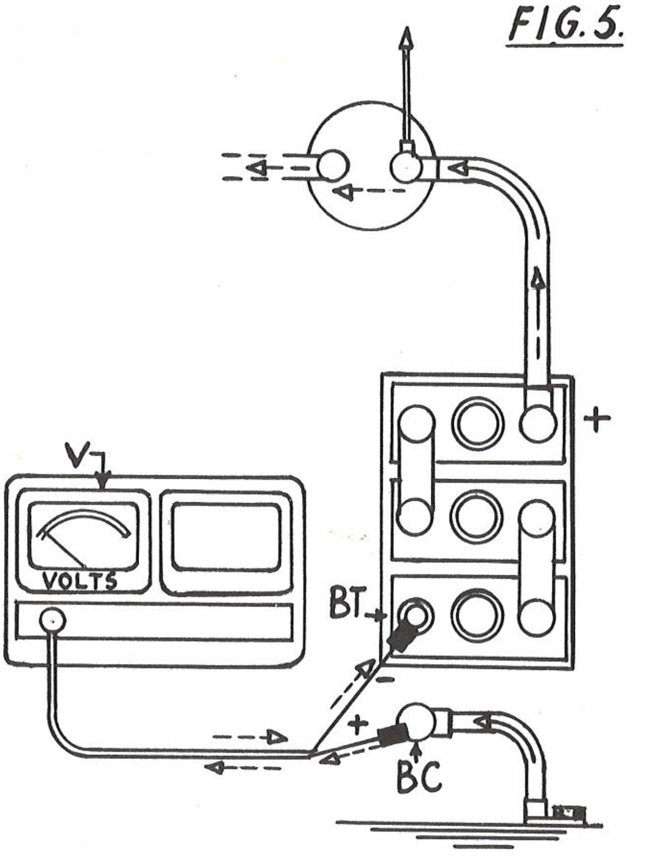

V
VOLTS
+
BT
-
+
BC

FIG. 6.

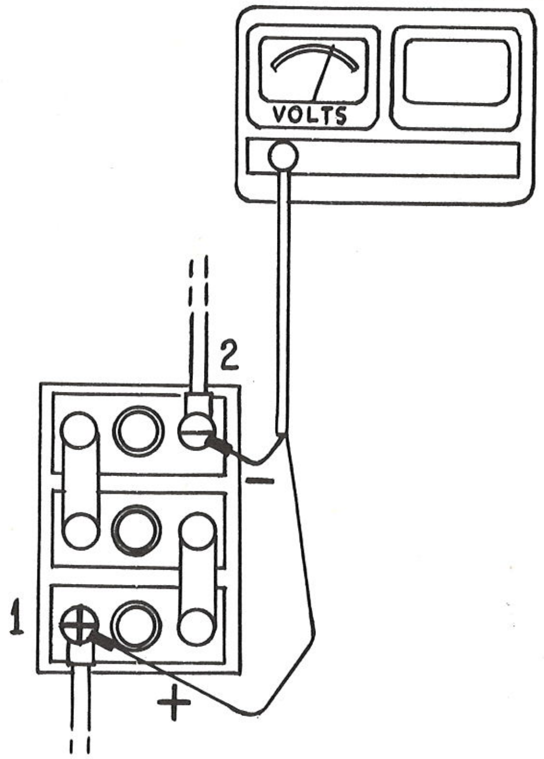
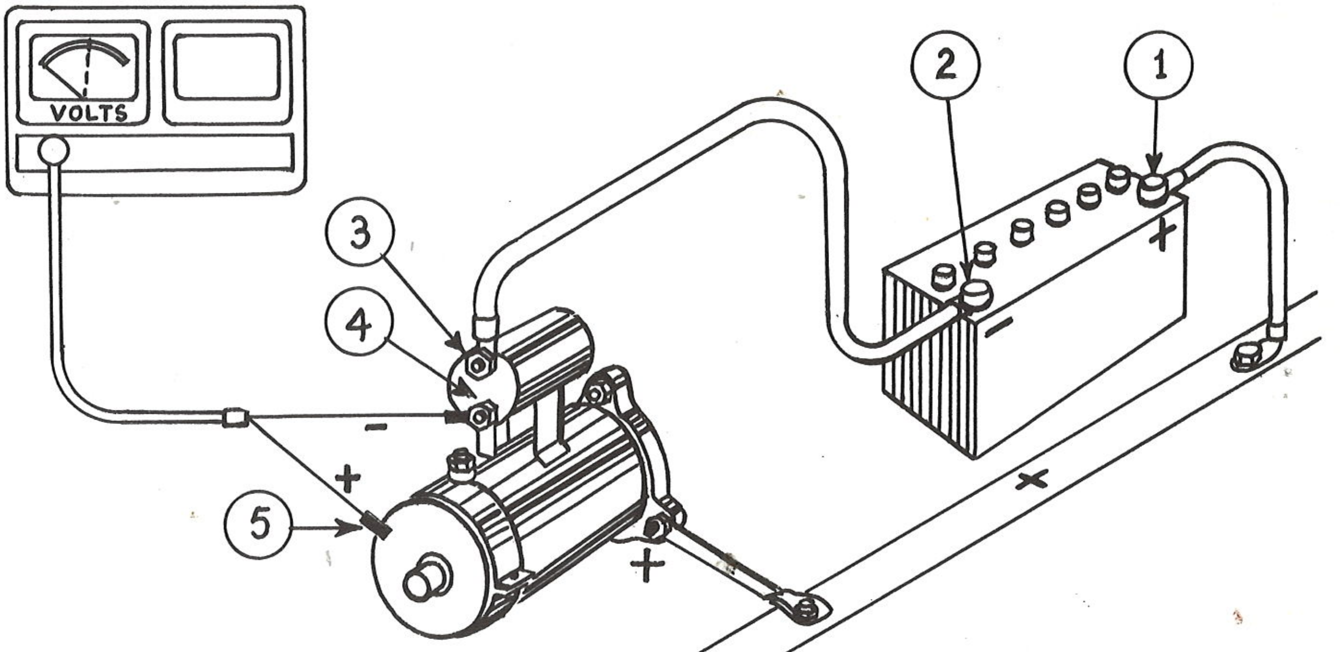


FIG. 7.


VOLTS
3
4
-
+
5
+
2
1
-
+
+

is operated. See that the voltmeter is set for the correct range, i.e., 10V for 6-volt equipment or 20V for 12-volt equipment and that the leads are connected in correct polarity. Where it is necessary to switch on ignition to operate the starter switch connect a "jumper" lead from the distributor terminal to earth. For satisfactory operation the voltmeter should read not less than 5 volts for a 6-volt system or 10 volts for a 12-volt system, and the starter should spin the engine at a steady uniform speed, with no intermittent clacking or grinding and the drive should engage quietly and promptly.

If the starter turns with a slow and labouring operation it indicates that the starter is either starved of electrical energy through current being wasted because of faulty insulation, or is overloaded. If there is an intermittent clacking or grinding sound, it indicates a damaged gear ring.

If, when making the tests, the voltage is not less than 5 volts or 10 volts and starter operation is slow or laboured, it shows that the slow running is due to current starvation at the starter. Voltage is being lost in the starter circuit because of unfuly high resistance. The voltage drop tests which follow will confirm this diagnosis and tell you the site of the fault.

If the voltage falls heavily, perhaps down to 3.5 or 7 volts while the starter is engaged, it is a sure indication that a very heavy current is flowing. By using an external ammeter shunt designed to carry up to 500 amperes, this current can be measured by connecting the shunt in series with the battery earth line as illustrated in Fig. 6A.

If laboured starter operation or heavy current consumption is indicated, it is necessary to ascertain the reason. Either the engine or clutch is partly seized (this can be verified by hand cranking) or the starter armature may be rubbing on the pole shoes, or some other cause. The second possibility is faulty insulation, allowing current to leak away and lowering the voltage applied to the starter.

Remove the brush cover band if possible (otherwise remove the starter) and check the condition of the commutator and brushes. Either on the vehicle or on a Test Bench, operate the starter with the cover band off and note any heavy sparking, burning or wisps of smoke from inside. Also observe if there is a heavy deposit of copper dust on the inside of the cover.

If the armature is normally free, you may be able to turn it with your fingers (turn against direction of rotation). In the event of seizing, heavy copper deposit, worn brushes or evidence of short circuiting within the starter, it must be removed for shop service or a reconditioned starter fitted.

TESTING VOLTAGE AT STARTER.

Fig.7 shows the method of testing the voltage at the starter. Connect the voltmeter leads as shown (making sure the polarity connections are correct. The system illustrated has the positive battery terminal connected to the frame which is usual for modern systems.)

If the starter is not fitted with an external terminal on the starter side of the switch, it will be necessary to connect as shown in Fig.8 i.e., to the live terminal of the switch.

FIG. 6A.

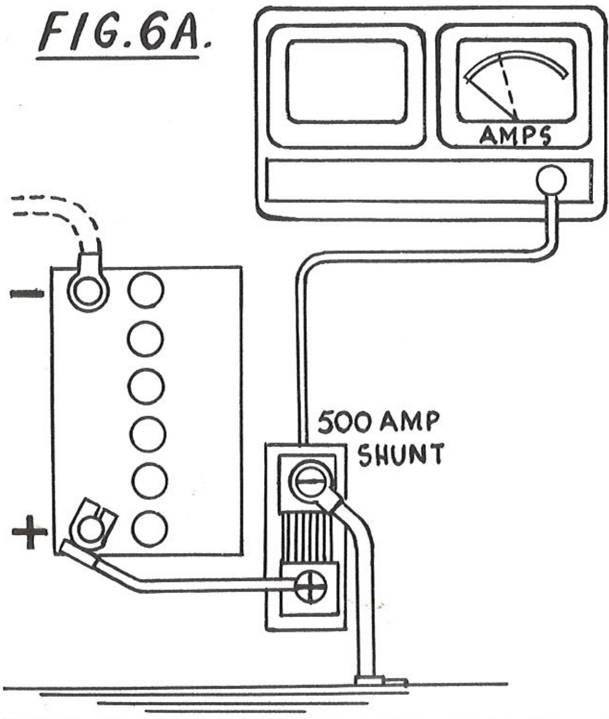

AMPS
500 AMP SHUNT
−
+

FIG. 8.

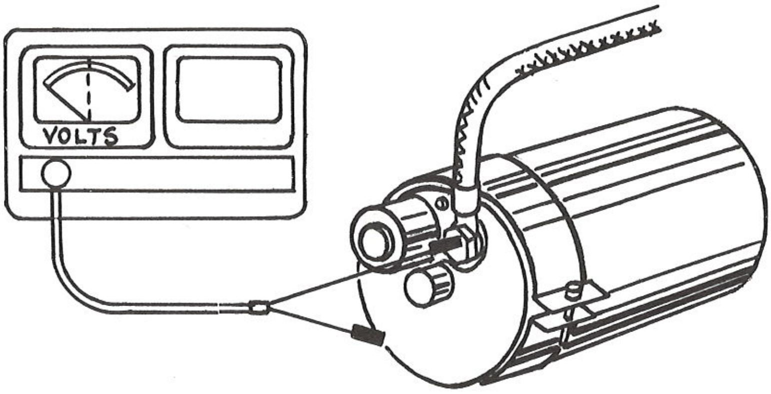


FIG. 9.

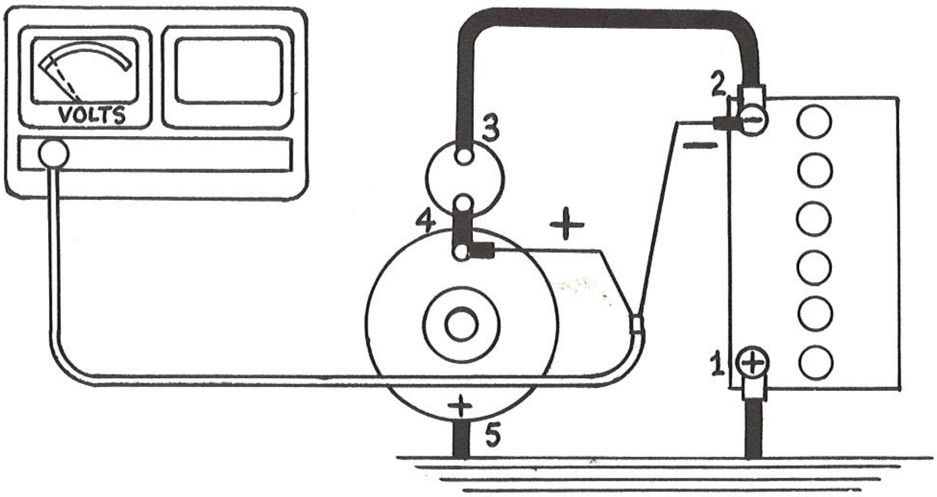

VOLTS
2
3
−
4
+
1
+
5

FIG. 10.

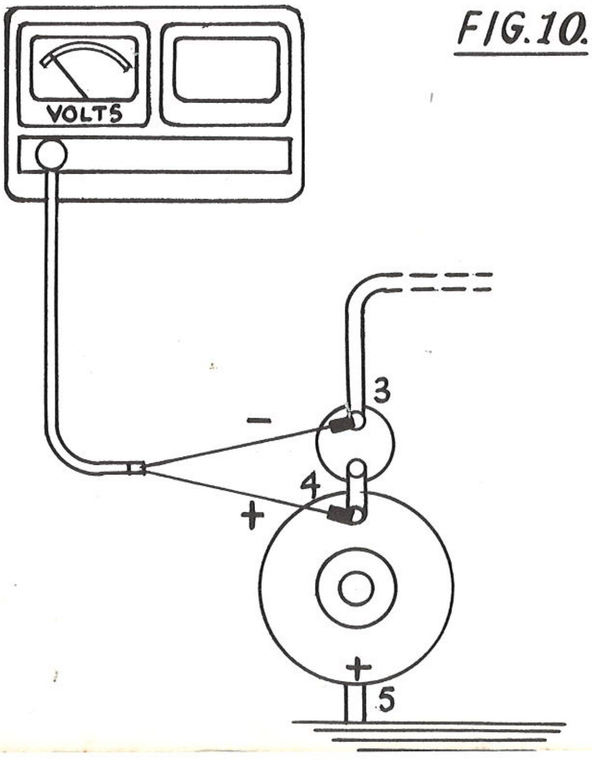
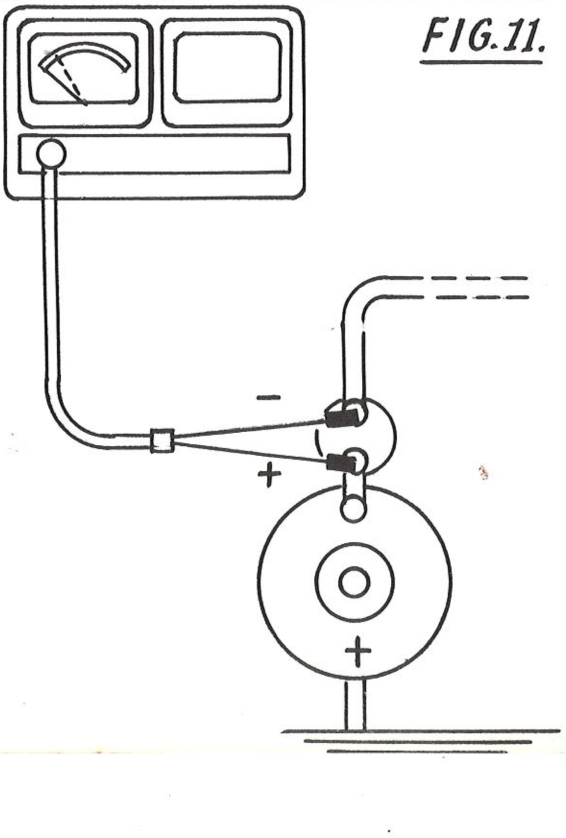


FIG. 11.



When the starter switch is closed the voltmeter indicates the voltage applied to the starter. This reading should be not more than ½ volt lower than the previous battery voltage. This ½ volt is the maximum total voltage drop allowable in the cable from the battery to the starter.

When making the test close the starter switch, take a quick reading of the voltage and then release the switch immediately.

If the connection is made as shown in Fig.8 a voltage reading of ¾ volt is permissible because allowance has to be made for the voltage drop in the starter switch.

TESTING STARTER SWITCH AND MAIN BATTERY TO STARTER CABLES.

Fig.9 shows the connections for testing the battery-to-starter switch cable and the starter switch itself. The polarity connections shown are also for a battery with positive earth connections. If the battery has its negative terminal earthed, the connections should be reversed.

When the voltmeter is first connected it will read the full battery voltage. The starter switch is now closed, when the starter will operate and the voltmeter reading should drop to practically zero. To read the low voltage accurately, operate the 1 volt range switch, note the reading quickly, then release the 1 volt range switch before you release the starter.switch. The maximum voltmeter reading should be within ½ volt. If the voltmeter reads higher than ½ volt it shows high resistance in the circuit, which can be checked as shown in Fig.10. This tests the voltage across the starter switch and the connection between the starter switch and the starter. If a repeat test shows the same high voltage reading, you can identify the faulty section by connecting the voltmeter as shown in Fig.11. If a repeat test still shows high voltage the switch is faulty; if the reading is now ½ volt or less the trouble is in the cable or strap from the switch to the starter or to the connections at either end of this cable.

TESTING BATTERY TO STARTER CABLE.

Fig.12 shows the method of testing the cable from the battery to the starter. With the starter operating the voltmeter reading should not exceed 1/10th of 1 volt. If the reading is higher, inspect for loose or corroded connections, badly soldered sockets, or undersized cables. Bad contacts will cause local heating which will also help in locating the trouble.

TESTING EARTH CONNECTIONS.

Fig.13 shows the method of testing the battery and starter earth connections. The test includes both the connections to the vehicle chassis and covers the whole of the earth return path. With the voltmeter connected as shown and the starter operating, the voltage reading should not exceed ½ volt. If the reading is higher, the location of the trouble can be tested by making further voltmeter tests as shown in Figs. 14 and 15. Fig.14 shows the method of testing the starter earth connection and Fig.15 the battery earth connection. A jerky reading when the engine is turning indicates an intermittent bad contact - this can be due in the engine bonding section.

FIG.12.

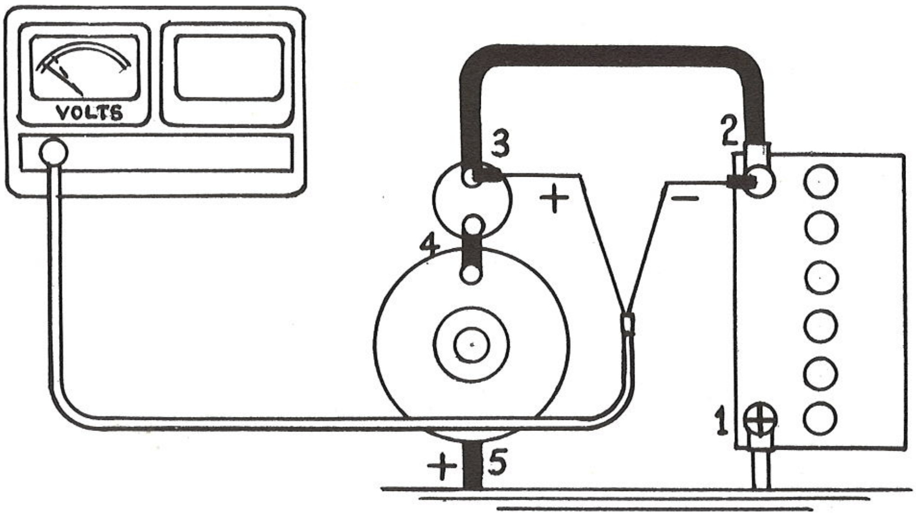

VOLTS
3
2
+
−
4
1
+
5

FIG.13.

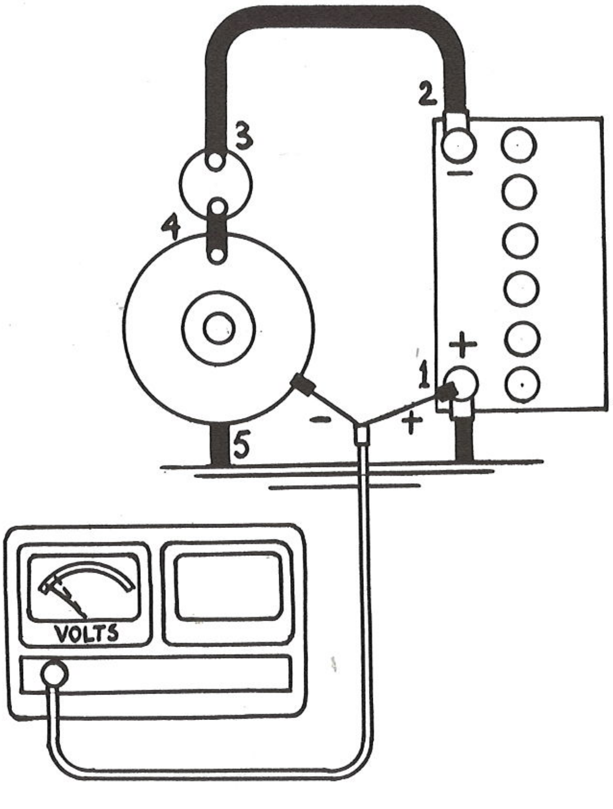
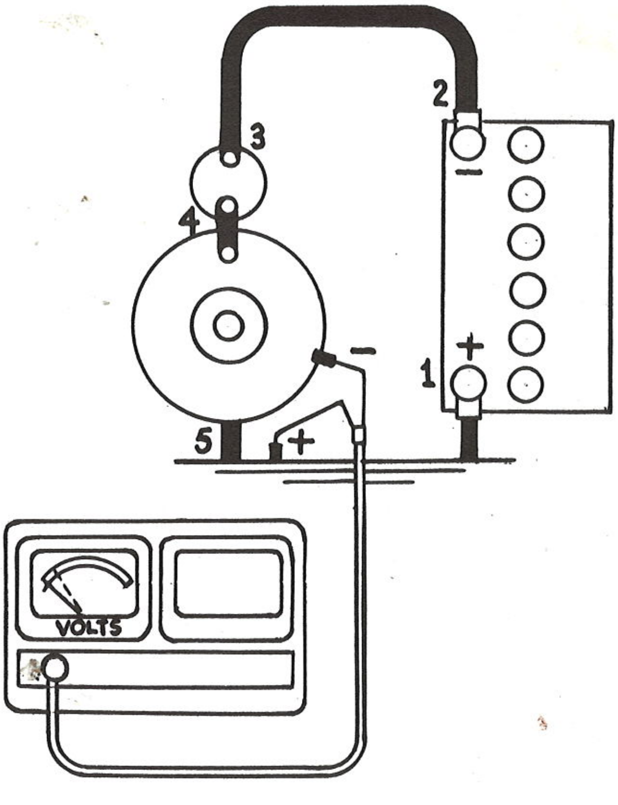

2
3
−
4
+
1
−
+
5
VOLTS

FIG.14.


2
3
−
4
−
+
1
5
+
VOLTS

STARTER CONTROL CIRCUITS.

There are various methods of operating the starter switch. Simple hand or foot operated switching is replaced by solenoid operation in many modern vehicles and the same solenoid may be used to engage the drive. Fig.16 illustrates a basic solenoid control circuit, where the operation of a light spring push switch (P) operates the solenoid starter switch. The supply to the solenoid is usually taken via the ignition switch (IG) and ammeter (A) as a safety measure so that when the ignition is "OFF" the starter circuit cannot be operated.

SAFETY LOCK-OUT DEVICES.

Many vehicles are fitted with locking devices to prevent the starter being engaged when the engine is running. The type of locking device fitted must be ascertained from the service information provided with the vehicle. The general principle is shown in Fig.17 where the Locking Device is in the form of an additional switch or contactor, connected in series with the solenoid control circuit.

This switch or contactor (L) is normally closed so that when the ignition switch is "ON" and the starter push switch (P) is operated, the closed circuit via wiring sections 1 to 5, conveys current to the starter solenoid switch and operates the starter.

When the engine is started and is running above a pre-determined minimum speed, the lock-out contactor is opened, usually by means of a vacuum unit. This opens the control circuit and even if the starter push switch (P) is operated, no current will flow to the starter solenoid switch, which is therefore inoperative until the engine is stopped.

An alternative arrangement used on many American vehicles is shown in Fig.18. In this case the circuit is wired to a contactor (L) in the regulator. When the engine is running the generator (G) voltage opposes current flowing in the starter solenoid and the action of the cutout opens contacts (L). This means that so long as the engine is running and the generator charging the starter switch cannot be operated.

TESTING STARTER CONTROL CIRCUITS.

Sometimes when making the first test of the starter circuit, namely, testing the battery voltage with the starter operating, there will be a complete lack of response of the starter and no change in the battery voltage. This indicates a defect in the starter control circuit.

To test the control circuit connect the voltmeter as shown in Fig.19. If the voltmeter reads the normal battery voltage when the push switch is closed, it shows that the trouble is in the starter solenoid or its earth return path.

When testing a starter of the type shown in Fig.18 connect a jumper lead from the second terminal to earth as shown at (J) in Fig.20 to by-pass the lock-out. If the starter now operates, the fault lies in the return line and must be traced in accordance with the circuit layout of the system concerned.

If there is no indication of voltage with the voltmeter connected to the "SOL"

FIG. 15.

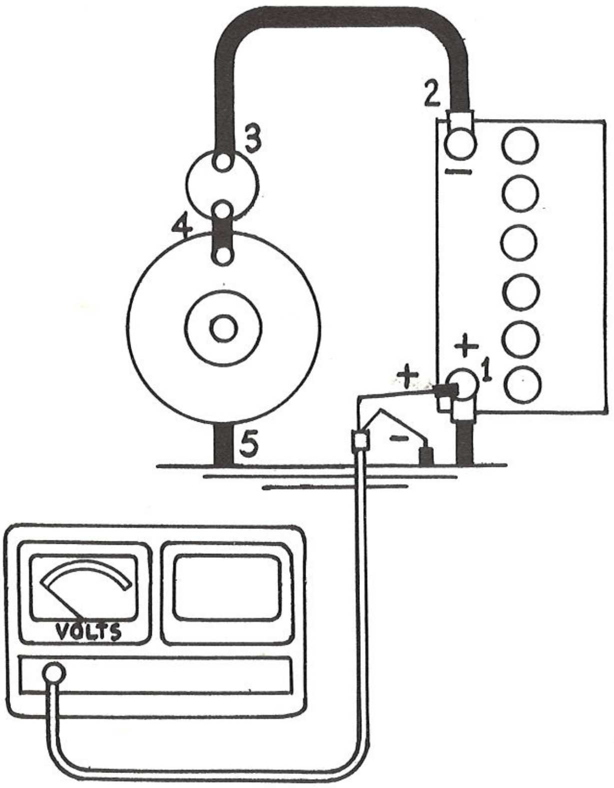

2
3
4
5
−
+
+
1
+
−
VOLTS

FIG. 16.

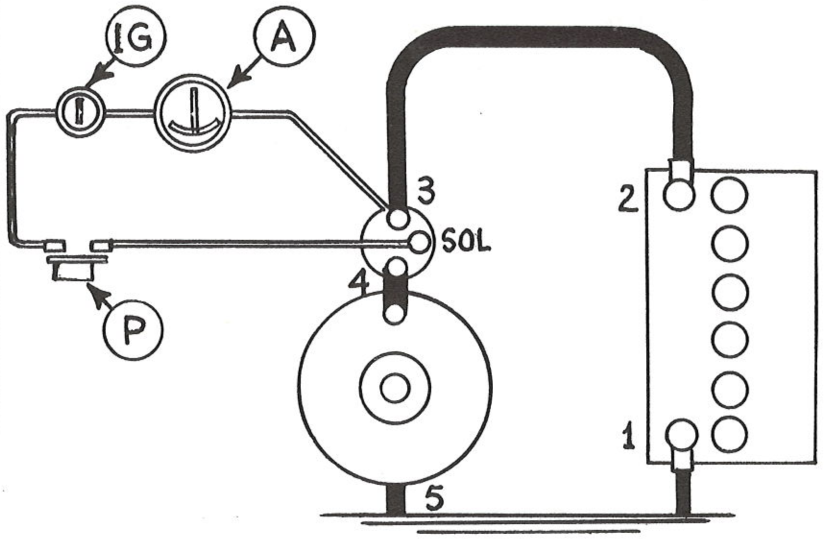
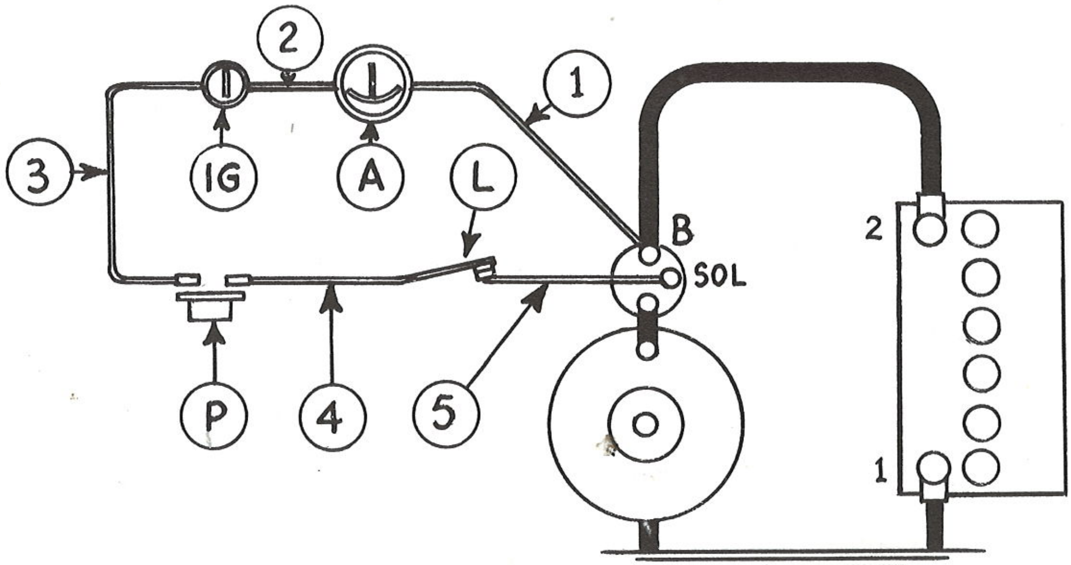

IG
A
3
SOL
4
P
2
1
5

FIG. 17.


2
1
3
IG
A
L
B
SOL
2
P
4
5
1

terminal as the push switch is closed and ignition is switched on, it indicates that the control circuit is open at some point between the main battery terminal and the "SOL" terminal. In some cases this can be proved by using a jumper lead (J) to bridge the circuit as shown in Fig.21. If the starter operates normally as soon as the jumper connects the terminals shown, the fault in the control circuit must be located by tracing back from point to point, which is a normal electrical service job.

If pressing the push switch results in a clicking sound in the main switch but the starter does not run or engage, it indicates that the main solenoid is not closing its contacts, and the switch or starter must be removed for service.

In a case where the switch is separately mounted and is connected by cable to the starter terminal the faulty unit can be identified as shown in Fig.22. Connect voltmeter lead to point No.1 to check continuity of switch, or to point No.2 to check cable at starter. The clicking sound indicates that the switch movement is operating but the main circuit is not closing. The voltmeter is connected as shown when its reading will locate the reason for the open circuit, i.e.,

(a) A reading of battery voltage when the switch is operated indicates that the switch is closing but the circuit through the starter is open, due to sticking brushes, broken connection, or some other reason which requires the removal of the starter for service.

(b) When the voltmeter shows no voltage at the starter terminal it shows that the main switch is not closing even though the action of the solenoid may be heard. The starter switch must be removed for service.

Instances may be experienced where operation of the starter push switch results in a loud repeated clacking noise with a big drop in the voltage reading across the battery. This is due to a high resistance contact in the main circuit, most usually at the battery terminal. This causes the voltage to drop steeply as the load of the starter is applied, which in turn causes the solenoid to be starved of voltage so that it releases and opens the contacts. When eased of the starter load, the voltage rises again, and the process is repeated rather like a low frequency buzzer. If inspection does not show where the bad connection lies, then the drop tests carried out in the manner described will indicate where the fault is located.

THE IMPORTANCE OF SYSTEMATIC ANALYSIS.

If the tests described in this lesson are carried out thoroughly, you cannot fail to locate the reason for any loss of voltage in the starter circuit. The voltmeter is used for every test and is therefore an indispensable instrument for starter service. The ammeter is also used where it is required to test the actual starter current consumption from the battery for which purpose a shunt must be used because of the high value of the current.

Always remember when testing the starter and starter circuit that the inertia and drag of the engine will vary considerably with temperature and other conditions. Starting from cold is the nearest we can get to a constant normal load.

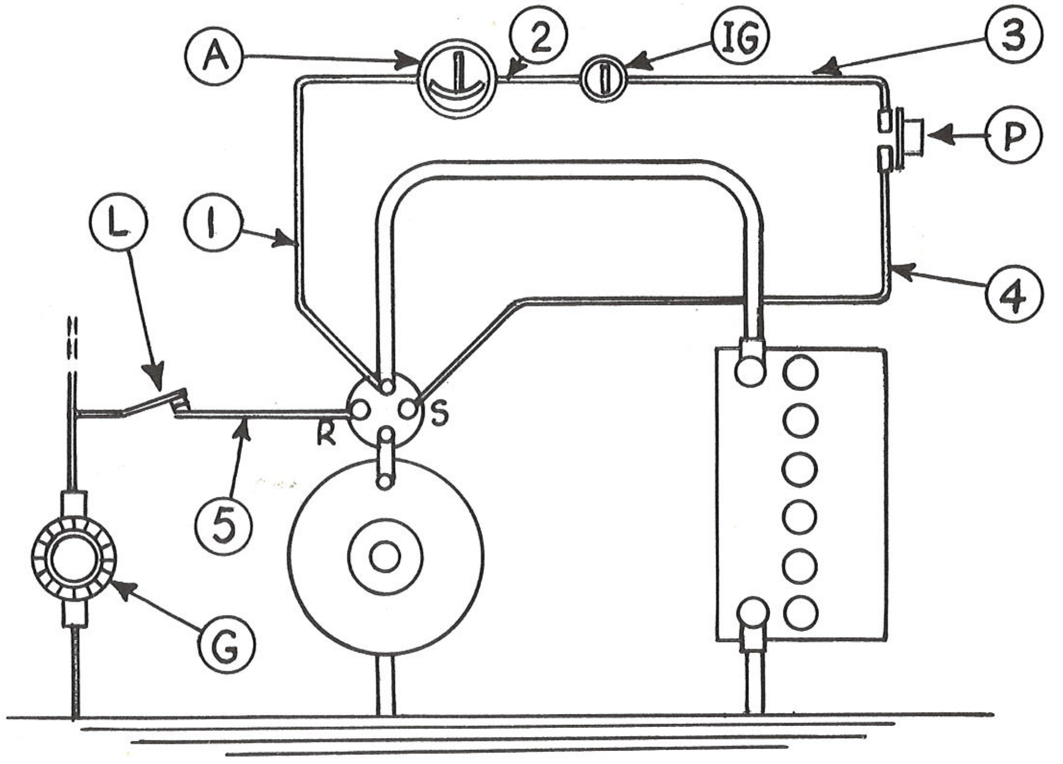

A
2
IG
3
P
L
I
4
S
R
5
G

FIG.18.

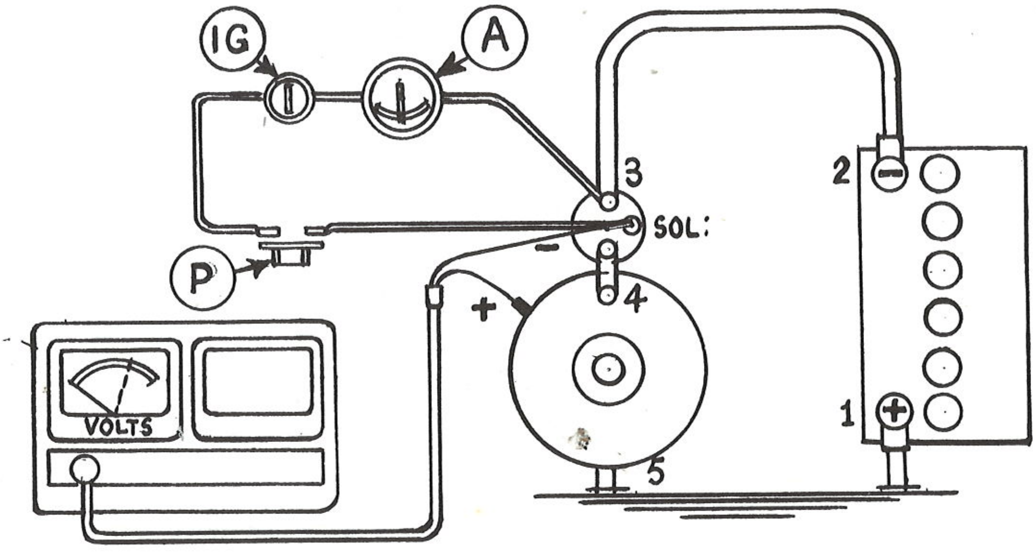

IG
A
3
2
SOL:
P
−
+
4
VOLTS
1
5

FIG.19.

If there is any doubt about the starter unit it should be removed and tested independently on a Test Bench equipped with a suitable lock torque testing feature. This enables a constant and measurable load equal to the most arduous service duty to be applied to the starter, and the Test Bench instruments simultaneously indicate all electrical conditions, resulting in a test far more comprehensive than can be carried out on the vehicle itself.

SUMMARY.

To recap. the information given in this lesson, we summarise as follows:-

(1) Always start testing with the battery and its connections. Make sure that the battery is healthy and fully charged - if not charge the battery or fit a replacement fully charged battery.

(2) Do not omit the battery leakage test even if you have no reason to suspect any leakage.

(3) In the case of a complete failure of starter operation where the starter is fitted with solenoid control, locate and clear the fault and then proceed to test the main circuit. It is often possible to rig up a "jury" circuit with temporary wiring to replace a faulty control circuit so that the diagnosis can be completed and the owner given a full report.

(4) If it is found that the starter unit is defective and you are authorised to remove it for repair or replacement, proceed to complete your diagnosis of the entire system with a replacement unit fitted, because there may be other faults which you can only test and locate with a healthy starter unit, for example, high resistance connections to earth or the battery.

(5) Always follow the procedure laid down in this lesson and given in precis form in the "Cryptoscope" and do not be deflected from any test in the complete sequence until the operation is concluded.

(6) When testing the starter take all voltmeter readings quickly and then release the starter switch to avoid prolonged starter operation.

(7) After completing the starter test always, if possible, give the battery a boost charge.

FIG.20.

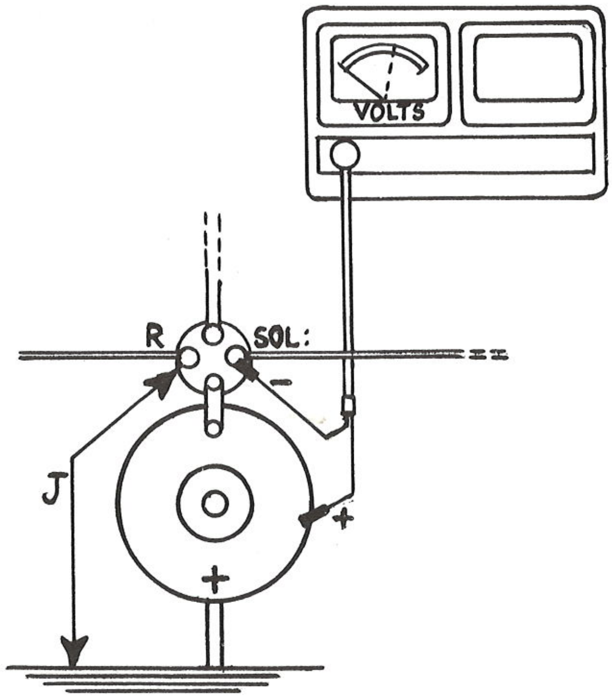

VOLTS
R
SOL:
J
+
+
−

FIG.21.

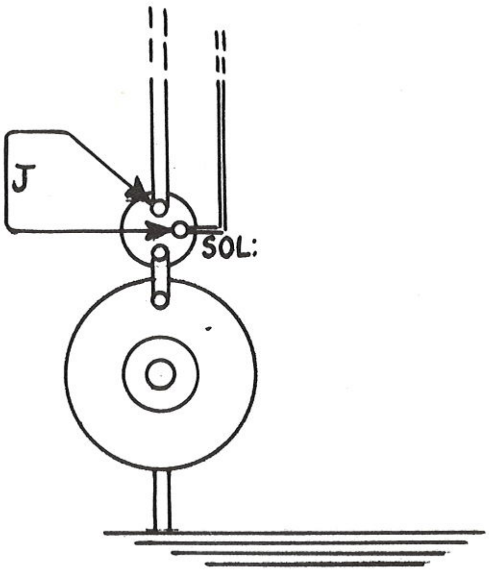
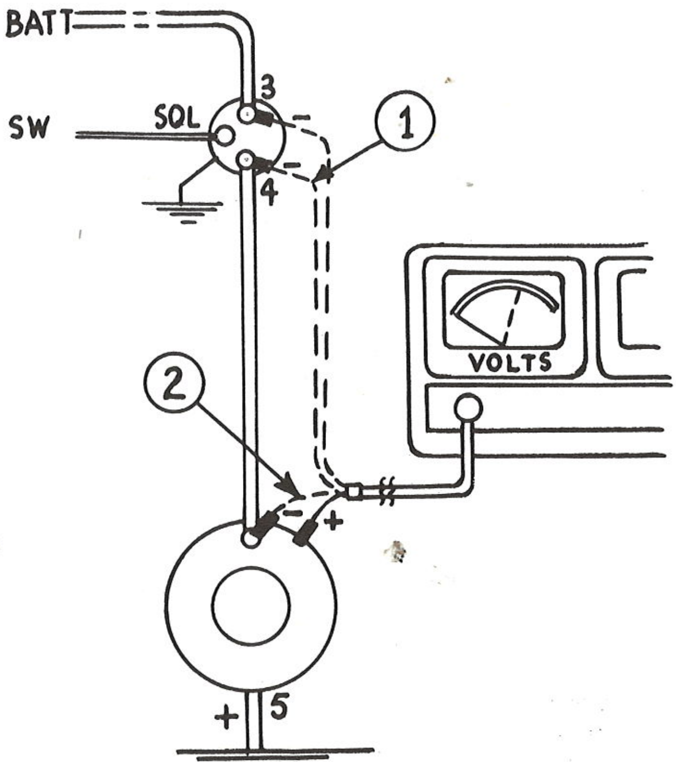


FIG.22.


BATT
SW
SOL
3
4
1
2
VOLTS
−
−
−
+
+
5

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 8

THE AUTOMOBILE GENERATOR

What to Know About the Operation
and Testing of Modern Generators.

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

THE GENERATOR

In the previous lesson we treated the starting system as a group of components working as a team, with the starter itself as one unit in the system. The same principle applies to the charging system which consists of a set of units which must function jointly in an efficient manner for the system to operate correctly.

There, however, the similarity ends. We have to check the starter in conjunction with other sections of the system but in the case of the generator we can make independent tests to determine its condition, regardless of the state of the rest of the system. Wider variations in generator design as compared with starters, make it necessary to suit the test connections to the type of machine concerned. For these and other reasons we are devoting a complete lesson to the generator before going on to deal with the regulator and other sections of the charging system.

THE DUTY OF THE GENERATOR.

The generator is driven by the engine and absorbs a small proportion of the horsepower which it reproduces in electrical form suitable for recharging the battery and supplying the requirements of other equipment. If the output of the generator fails or falls below the minimum required, the battery will make up the difference for a time and there will be no immediate electrical failure. This is only achieved, however, by drawing on the reserve of energy in the battery which is limited by its capacity and the load in use. Unless the generator trouble is corrected the battery will soon become discharged with no replenishment forthcoming and then everything will fail in regular sequence, commencing with failure of the starting system, followed by lighting failure, the non-operation of electrical accessories and finally failure of ignition to start the engine, even when hand cranked.

Few car owners know anything of the generator or its function and a failure is only diagnosed when the vehicle is brought in with a complaint that one or the other symptom has appeared such as "the battery is discharged" or "the generator is faulty". Having tested the battery and determined its condition as our first precaution, we then have to locate the fault in the generator or elsewhere.

PRIMARY DRIVE AND GENERATOR LOAD.

The generator consists of a frame or carcase bolted to the engine block, enclosing the rotary armature, having a steel shaft carried in bearings located in the end plates of the frame. A 'V' grooved belt pulley on the outer extension of the armature shaft is coupled to a similar pulley on the forward end of the engine crankshaft or camshaft by means of a 'V' belt. The same belt may also engage a third pulley on the shaft of the fan or water pump.

FIG 1A.

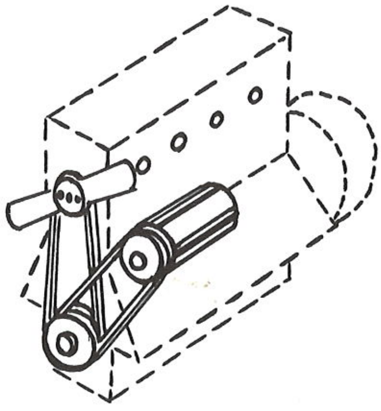


FIG 1B.

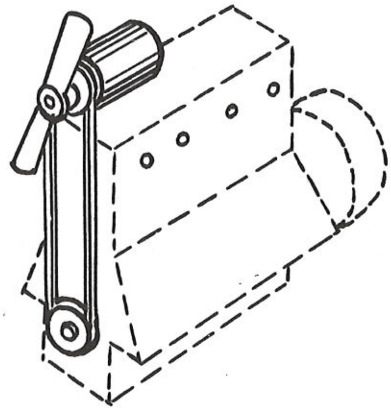


FIG 1C.

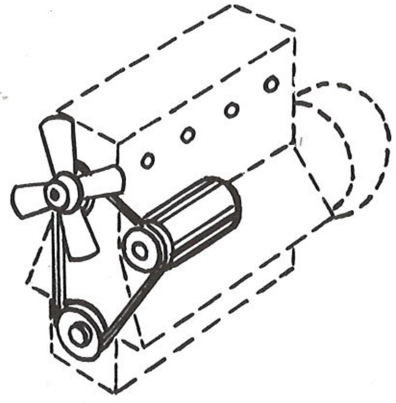


FIG 1D.

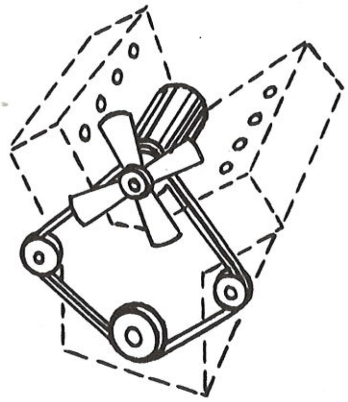


Fig.1 shows some variations of the belt pulley drives now commonly employed.
Fig.1A shows separate drives for fan and generator.
Fig.1B shows fan blades mounted on the generator shaft.
Fig.1C shows a three point fan and generator drive.
Fig.1D shows an arrangement used on 'V8' engines with generator, fan and two water pumps.

In the three point drive in Fig.2 the driving pulley on the engine is No.1, the generator pulley No.2 and the fan or pump No.3.

The greater the power output of the generator at a given speed, the more drag or resistance to rotation will be exerted by the armature. This drag absorbs the mechanical power transmitted by the belt and pulleys and the generator reproduces this power in electrical form. The speed of the generator armature (neglecting belt slip) will be that of the engine multiplied by the ratio of the effective diameters of pulleys 1 and 2. The frictional cohesion between the belt faces and pulley flanges must be sufficient to resist slipping under maximum load. When the pulleys and belt are in good condition and the frictional surface is not worn or polished by persistent slipping, the frictional grip is determined by belt tension. Fig.3 shows the provision for tension adjustment where the generator carcase has lugs A and B securing it to the bracket C which is fixed to the engine block. A third lug D is bolted to the slotted bar E which is also bolted to the block. By slackening the bolt the belt tension can be increased to the required degree and the carcase secured in its new position by tightening the bolt.

EFFECTIVE BELT SLIP.

Wear or belt slackness will alter the speed ratio under load. The result will be loss of driven-pulley speed and consequent fall of generator output at any given engine speed. Rapid wear of the belt and pulleys will follow and reduced output will eventually starve the electrical system of power. Once the belt has worn narrow it will finish up by riding on the flat bottom surface shown at B in Fig.4. This bottom contact between belt and pulley will not provide enough frictional grip, however much the tension is increased and the worn belt or pulleys must be replaced.

It is important to check the belt drive as the first check in making a diagnosis and inspection of the charging system. Belt surfaces must be in serviceable condition with pulley faces not unduly polished and the belt should ride high in the groove without excessive tension. There should be about 1 inch of "whip" in the centre of the longest stretch between the pulleys when checked by manual pull and push. Pulley bottom surfaces must not be polished as the belt must ride clear; the belt width should be uniform throughout its length. This can be verified by watching the belt running over the generator pulley while the engine is idling. Uneven wear will be shown by the belt riding up and down in the groove as its width varies.

GENERATION OF ELECTRICAL ENERGY.

Fig.5 shows a basic generator carcase in the form of an iron cylinder having shaped blocks or "pole shoes" internally secured on opposite sides. The carcase F has the pole shoes P1 and P2 and the curved faces form a central tunnel. This iron structure is magnetised with the magnet poles located as

FIG 2.

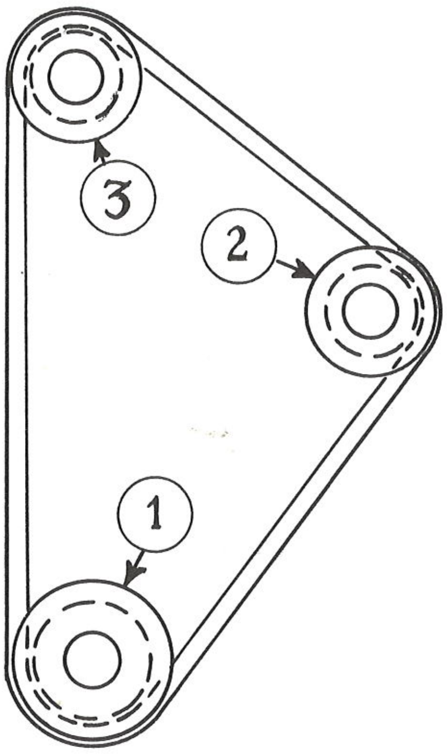


FIG 3.

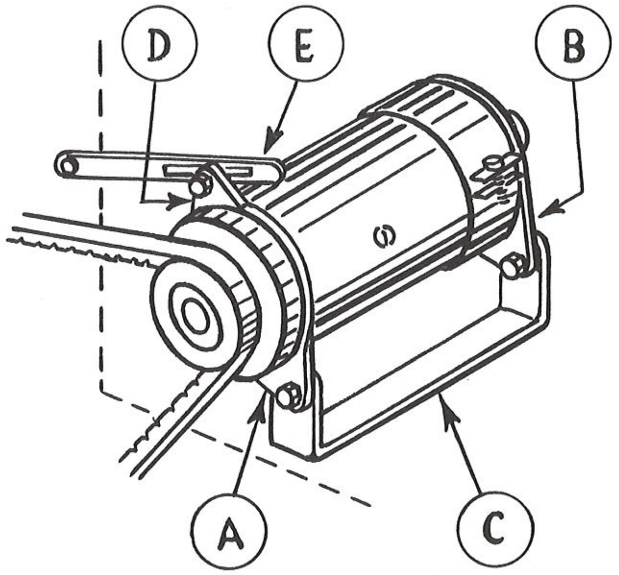


FIG 4.

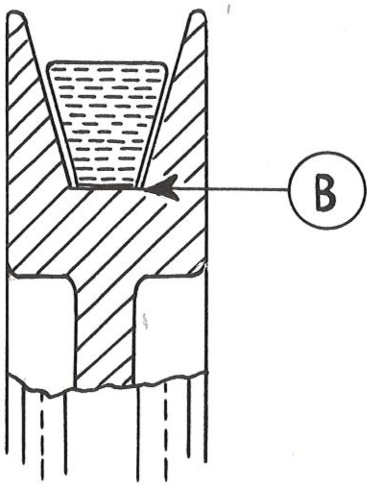
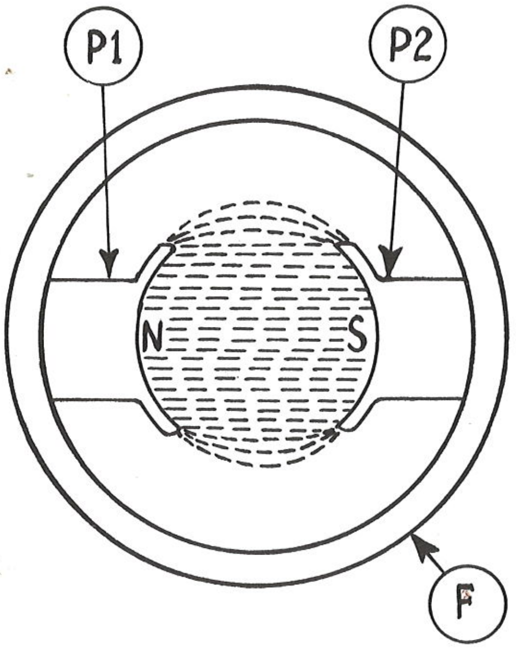


FIG 5.



shown at N. and S. The field space between the poles is occupied by magnetic lines of force extended like tight strings between the pole faces. You have seen the form of these lines by the familiar experiment with iron filings spread on paper with a magnet placed underneath.

In Fig.6 the armature is shown located in the field space, the shaft S carrying a laminated iron drum D having slots in which are located a number of copper wire coils C. The ends of the coils are connected to copper bars B embedded in a cylinder of insulating material forming the "commutator". The armature assembly rotates in its bearings and clears the pole faces by a very small air gap.

With the engine running the armature is driven at a uniform speed. As each coil on the armature is moved across the N pole face its turns "cut across" the lines of force and the voltage surge is generated in the coil, appearing at the commutator bars to which the coil ends are connected. The voltage surge in each coil dies down as the coil passes across from the N pole towards the S pole but when passing the S pole a second voltage surge is generated, this being reversed so that the commutator bar previously positive now becomes negative and the previous negative becomes positive. This surge in turn subsides in the second half of rotation and the cycle is repeated as the coil turns again past the N pole face. The same thing occurs in each coil in turn as the several coils follow each other, and we get a series of voltage surges building up and subsiding, according to the coil positions in relation to the pole faces.

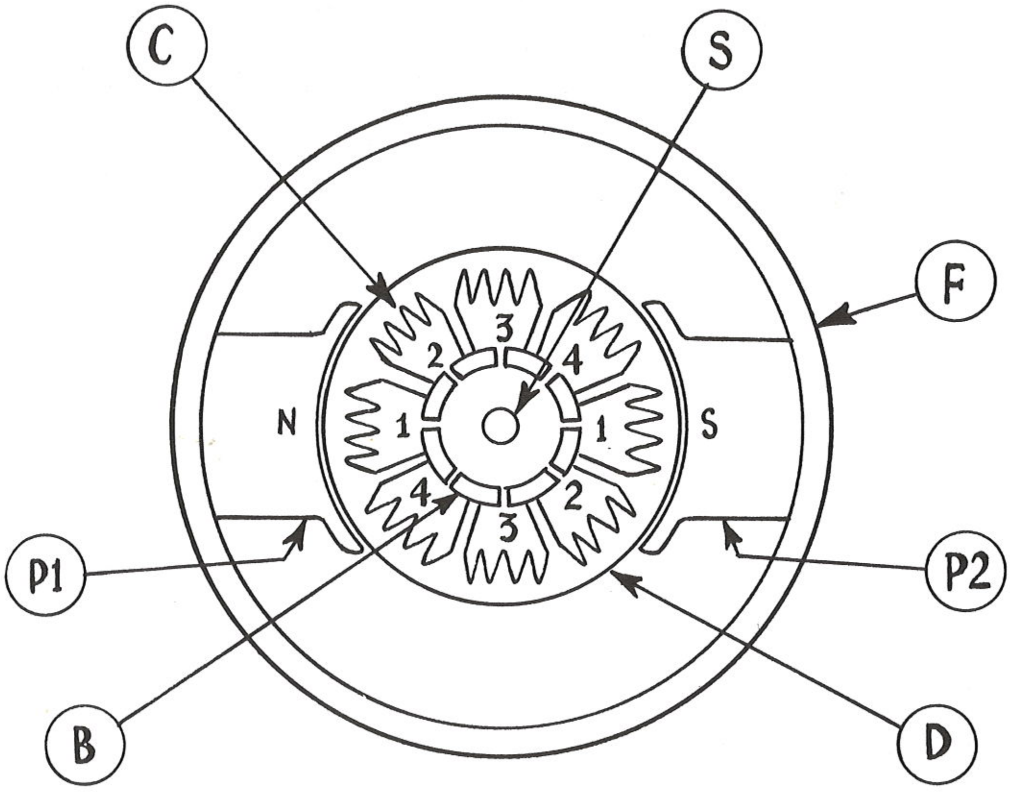
Fig.7 is a diagram of the voltage cycles generated in the four pairs of coils shown in Fig.6. This continuously changing and reversing voltage is known as "Alternating" and is not suitable for battery charging or power supply to vehicle equipment. The voltage must therefore be "rectified" which is effected by the commutator which rectifies the current or makes it uni-directional and it is conveyed via the brushes to the stationary generator terminals.

Fig.8 illustrates the commutator with its carbon brushes. The position of brushes relative to the pole shoes is such that one is on the bar at maximum positive and the other on the bar at maximum negative voltage. As the coil connected to these bars moves out of the dense area of the magnetic field and its voltage declines, its bars also move from the brushes and are replaced by the next pair to which the next coil to move into the dense magnetic area is connected. This means that all the peak voltage surges are picked up by the brushes at their maximum point and the brushes always remain of the same polarity. This is indicated in Fig.8 where the positive and negative signs on the commutator bars are drawn heavier at the maximum points with the bars at zero voltage shown "0".

GENERATOR RESIDUAL VOLTAGE.

When the generator armature starts to turn, a small voltage will be generated which increases as the generator comes up to speed. The initial voltage is due to a small amount of magnetism residing in the iron of the carcase and pole shoes. This is known as the "residual" magnetic field. It is virtually constant in density and the voltage generated will vary only with armature speed.

FIG 6.



C
S
F
3
2
4
N
1
1
S
4
2
3
P1
P2
B
D

FIG 7.

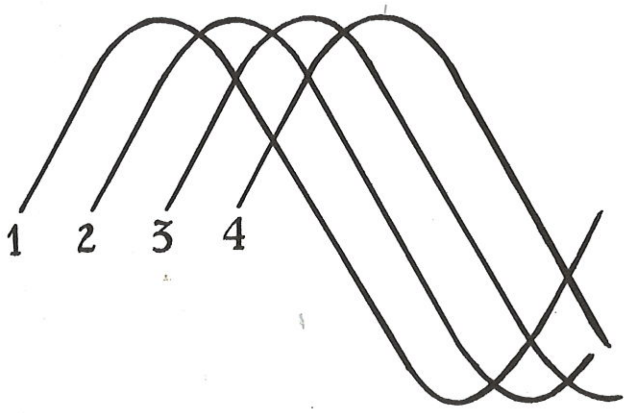
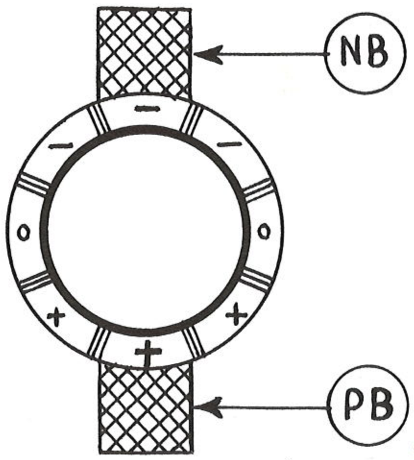


FIG 8.



It is essential that there is a residual magnetic field of correct polarity. If, for any reason, the iron frame and pole shoes of the generator becomes entirely demagnetised the machine will fail to generate any voltage and will not start to "build up". If the residual magnetic field should be reversed in polarity, then the voltage generated will also be reversed and the positive brush will prove to be the negative end of the supply. Because of this the first test of generator function is to check the voltage while running on the residual magnetic field, and see that this field is adequate in strength and of the right polarity to start generating the correct power.

EXCITING THE GENERATOR FIELD BY ELECTRO-MAGNETISM.

The residual magnetic field is too weak to generate enough power for any practical purpose and its density must be increased.

Fig.9 shows that insulated copper windings FC.1 and FC.2 have been added to the iron pole shoes. These windings or field coils are connected in series and the outer end of one is wired to the positive brush and the outer end of the other to the negative brush as shown at PB and NB respectively. The positive brush is connected to the generator frame or carcase, this being the "Earth" terminal, and the negative brush is connected to an external terminal "T". The armature voltage is applied to the ends of the field coil so that the field circuit is in parallel with the armature.

The applied armature voltage causes a current to flow in the two field coils which induces a magnetic force in the pole shoes and supplements the residual magnetic field already present, thereby strengthening the total field density. This is known as "exciting the field" and provides a means of controlling the generator voltage.

With the generator started and initially generating voltage from the residual field, the armature coils begin to generate a higher voltage, which is applied to the field circuit, causing more current to flow and strengthening the magnetic field. This process continues until the armature is producing its maximum voltage for the speed at which it is running. This is described as running on a full field. If the speed of the generator is changed or if the resistance in the field and, consequently the field current, is altered there will be a variation in the generator voltage.

Correct resistance of the field circuit is not only important to ensure proper magnetisation at a nominal speed, but is also a vital factor in regulating the generator output. This will be dealt with in more detail in the following lessons. In all cases, however, it is necessary when making a diagnosis of the generator, to measure the field current which can be done by connecting a test ammeter in the field circuit whilst the generator is run at a speed which produces its nominal rated voltage of 6 or 12 volts. The ohmic resistance of the field circuit in most British automobile generators is approximately 6 ohms in 12-volt generators and 2 ohms in 6-volt generators. This results in an average field current of about 2 amperes in all types.

INDUCTANCE IN THE FIELD CIRCUIT.

A property of all electrical circuits including coil windings on iron cores is known as "inductance". Without going into the complex technical theory

FIG 9.

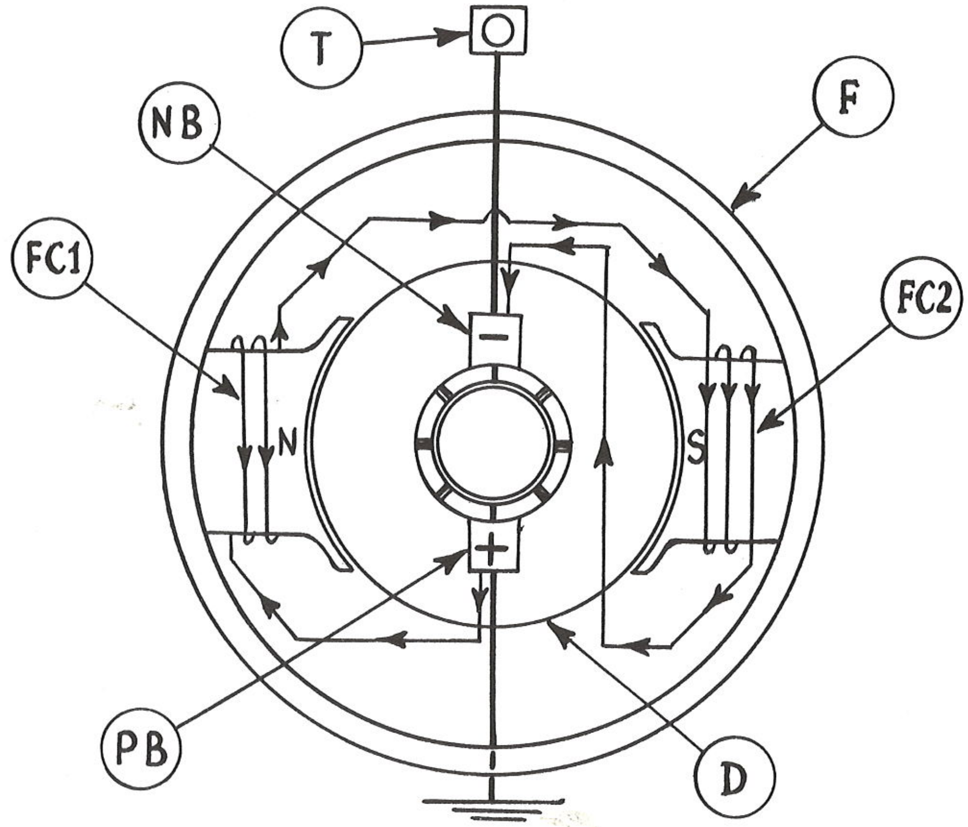
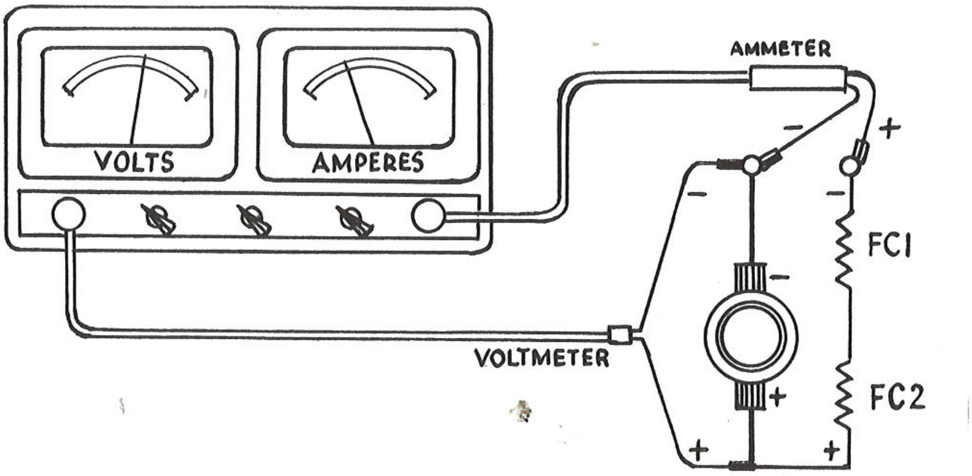

T
NB
F
FC1
FC2
N
S
PB
D

FIG 10.


VOLTS
AMPERES
AMMETER
VOLTMETER
FC1
FC2
+
−

of inductance we can, relatively easily, recognise its effect in a circuit. This effect is a form of electrical "conservatism" in that an opposition is exerted to any change in the current flow, the opposition increasing in effect with the abruptness of the change. If we increase the current value in the circuit quickly the "inductance" in the circuit will oppose and slow down the growth of the current. If we suddenly stop or slow down the current flow the "inductance" in the circuit will oppose this and tend to make the current continue to flow for a short time.

Inductance is determined broadly by the value of the current flowing, the number of turns of wire in the coils in the circuit and the mass and nature of the iron cores on which the coils are wound.

Fig.10 shows a test Ammeter connected in series with the field circuit to measure the field current and a test Voltmeter connected across the armature terminals to measure the voltage applied to the field coils. The polarity of the test connections should be noted.

If the generator is run from stand-still with these connections the Voltmeter will show the rising voltage and the proportionate increase of field current, both of which will remain stable at a constant speed. It is important that the speed is not increased beyond the point at which the voltmeter shows 6 volts or 12 volts, at which point the field current should be checked. If the generator speed is further increased the voltage and current will rise sharply at an increasing rate and overheating of both the armature and field coils will result.

The effect of inductance in the field circuit is most definitely experienced if we attempt to open the circuit suddenly when full field current is flowing. The current will tend to persist as the circuit is opened and a surge of voltage will be generated in the field coils, resulting in a current-bearing spark, or "arc", forming across the separating parts of the circuit. This will not only burn the contacts of the switch used to open the circuit, but also - and what is more serious - impose a high voltage on the field insulation and tend to break it down. In all full-field tests, therefore, the generator must be slowed down to collapse the field before the circuit is opened. This precaution is included in standard Crypton testing procedures.

TESTING GENERATOR POWER OUTPUT.

Manufacturers' specifications of generator performance includes data of the field resistance or the field current at nominal voltage.

The speed at which the nominal or "cutting-in" voltage is attained, the speed at which the full rated output of the generator is produced, the terminal voltage at this output, and the maximum current for which the generator is designed, must be in accordance with specification.

When testing a generator removed from the vehicle, these factors can be measured by running the generator in a test bench. Tests can also be made by measurements on the vehicle, when the generator output is tested in conjunction with the voltage regulator. If the output attains the maximum for which the regulator is rated, then the generator is serviceable. Information of testing the generator on the vehicle is given in detail in Lesson No.6.

FIG 11.

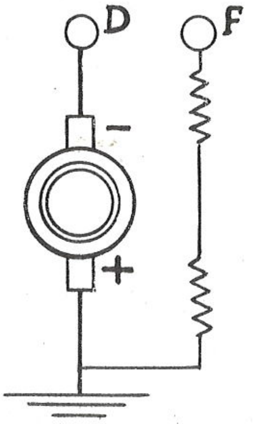


FIG 12.

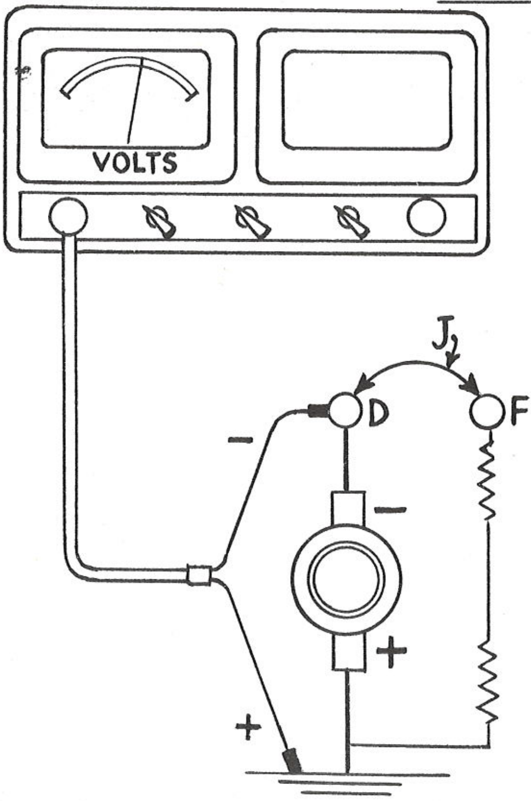


FIG 13.

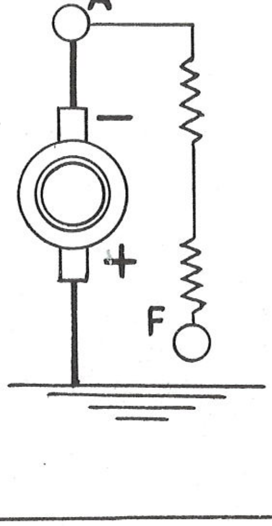
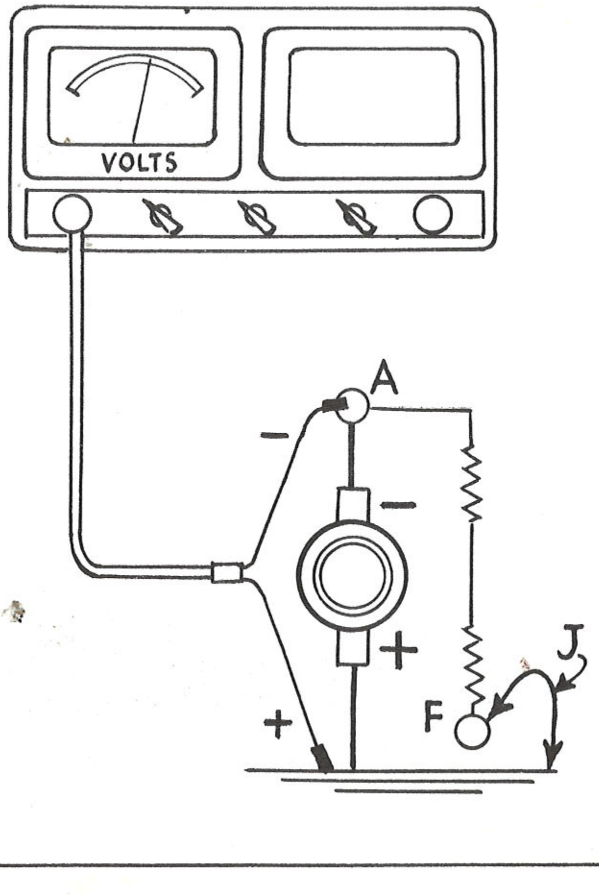


FIG 14.



GENERAL CONSTRUCTION OF GENERATOR.

Standard automobile generators follow the lines already described and comprise a cylindrical carcase frame or yoke, enclosed by end plates, the forward end-plate carrying the pulley-end of the armature shaft in a ball race with the rearward end supporting the commutator end of the shaft in an oil-less bush. The brushes mounted either in rocking holders or in boxes, in which they can slide, are held in contact with the commutator by springs. The tension of the springs is specified in the manufacturer's data and can be checked by means of a suitable spring tension gauge.

An impeller fan mounted on the armature shaft at the drive end creates a flow of air to cool the windings through apertures in the end plate.

Modern generators run at high speeds to generate the heavy power output required on present day vehicles, and accurate balancing of the armature with binding of the coils to prevent centrifugal "fling", has become a standard necessity.

FIELD CONNECTIONS AND TERMINAL ARRANGEMENTS.

The previous illustration Fig.9 shows how the field circuit is connected across the brushes, so that the armature voltage is impressed on the field winding. This arrangement, however, cannot be used in practice because the voltage will rise and fall with speed and will be out of control. It is essential to regulate the field current, and thereby the armature voltage, to maintain accurate control of the generator output independently of speed. This is done by the progressive insertion of resistance in the field circuit through the medium of a voltage regulator.

This means that part of the field circuit must be external to the generator for the connection of the voltage regulator, and connections to the voltage regulator have to be made from separate armature and field terminals on the generator.

Fig.11 shows the terminal layout of most British type generators. The armature terminal is marked "D" and one end of the field circuit taken to an additional terminal "F". The other field termination is taken direct to the brush of "Earth" polarity. The field circuit is not closed or completed until the "D" and "F" terminals are joined through the external regulator.

The field build-up can be tested independently of the regulator by detaching both cables from the "D" and "F" terminals, connecting these terminals with a jumper lead "J" and running the machine with a voltmeter connected across terminal "D" and the carcase as shown in Fig.12. When making this test the speed must be restricted to a safe voltage maximum, because the full field now connected removes all control other than the generator speed.

Connections of most U.S.A. generators are different to those used in British machines. Fig.13 shows a typical U.S.A. terminal layout. In this case the armature terminal bears the mark "A", the field terminal remaining "F". The internal connection also differs from British practice, the field connection being taken to the "live" brush instead of to the "Earth" brush, the circuit being completed by bridging the "F" terminal to Earth.

The voltmeter and jumper lead connections for testing U.S.A. type generators without the voltage regulator are shown in Fig.14. The jumper connections terminal "F" to Earth and the voltmeter is connected across the "A" terminal and Earth. In this case also the speed must be kept down to a safe voltage limit.

GENERATOR INSPECTION.

In addition to electrical tests, careful inspection also forms a part of all diagnosis procedures. The generator should be visually checked for evidence of present or impending defects. A check should be made of the drive belt and pulley and this should be followed by a more detailed inspection as follows:-

(1) Check terminals, wires and tags, and see that tags are properly soldered to cables, with no loose strands. Where pinch-screw terminals are used, verify that the connections are clean and tight.

(2) Check the generator mounting and see that the mounting bracket and bolts are secure. See that the pulley is secure on the shaft and the nut is tight. Examine the fan blades and mounting on the pulley. Check for end play or bearing wear. Check pole shoe screws and through-bolts.

(3) Remove the generator cover band and check for carbon dust on the inside surface which may be evidence of brush wear. Check the height of the brushes in their holders, and see that they are free to slide or move. Examine the spring mountings and note whether the springs are exerting free pressure on brushes, without rubbing on the boxes. Check the spring tension, if this is possible with the generator in position, and compare with service data. The correct spring tension varies but the average is 16 to 20 ozs. in small generators, up to 36 or 40 ozs. in large machines. Check the brush tags and terminal fixings and see that these, and the wires from the field coils, are not rubbing on the armature or commutator and are not being pinched inside the cover band. Check the commutator for surface ridging and discoloration.

Note whether the mica slots are choked with carbon dust or the micas standing flush or above the bars.

(4) With the engine running at idling speed, listen for the sound of the armature rubbing the pole shoes, for ball-race noise, brush squeak, or the rattle of anything loose inside. Lay your hand on the carcase and feel the vibration of any rough running.

(5) Now increase the engine to charging speed and observe commutation performance. Look for bright sparking at the trailing edges of the brushes indicating bad contact or commutator faults. Note if small sparks appear on the commutator surface away from the brushes which indicate inter-bar leakage of current through carbon dust in mica slots. A finger lightly placed on a brush will reveal uneven or eccentric commutator surface by the vibration.

SUMMARY.

To conclude this lesson the following are emphasised as the key points of generator diagnosis.

(1) First check the drive and make sure it is capable of transmitting the power at full load without slip.

(2) Make as complete an inspection of the drive and the generator as accessibility will allow.

(3) Check that voltage is generated on residual field and is of correct polarity.

(4) Verify the field current at nominal voltage.

(5) When testing on the vehicle run the generator at full output only in conjunction with the regulator.

(6) When tests are made without the regulator, connect the D and F terminals together for British machines or the F terminal to earth with U.S.A. machines and do not run the generator above its normal voltage.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 9

VOLTAGE AND CURRENT REGULATORS

What to Know About the Principles and Operation of Modern Regulators and their Testing and Adjustments.

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

VOLTAGE AND CURRENT REGULATION

We saw in Lesson No.4 that generator output must be controlled to suit the requirements of the vehicle electrical system. Being driven by the engine at widely variable speeds, the generator output would normally also be widely variable, causing possible overcharging of the battery and high voltage at the ignition coil, lamps and accessories.

It is essential that some means are provided for maintaining the generator output within acceptable limits which will -

(1) Keep the battery properly charged.

(2) Compensate for temperature conditions.

(3) Prevent the generator from being overloaded if the battery becomes low in charge or the load is heavy.

THE PRINCIPLE OF VOLTAGE REGULATION.

Fig.1 shows a simplified circuit of a shunt wound generator of the type discussed in Chapter 4, with its two terminals, the armature terminal "D" and the field terminal "F". The "D" terminal is usually connected to the negative brush of the armature and the "F" terminal to one end of the field coil, the other end of these coils being connected to the positive brush. The field terminal "F" is connected to a switch "C" in parallel with which is a resistance "R". When the switch "C" is closed current will flow through the field coils and we shall have a full field build up. As the generator speed rises its voltage rapidly increases. If, when the voltage begins to increase, the Switch "C" is opened, the field current will flow through the resistance "R". The insertion of this resistance will reduce the field current and cause the voltage to fall. If we then again close the switch "C", the voltage will once more begin to build up, and by repeated opening and closing of the switch, we can again cause the voltage to fall. By opening and closing the switch "C" very rapidly, we can hold the generator voltage reasonably constant.

When the switch contacts open, the current in the field circuit does not immediately increase, but builds up gradually, owing to the effect of self-induction as described in Chapter 4. The effect is seen in Fig.2 where, with the generator running and switch contacts opened, a resistance is switched out at the instant "T". The current in the field circuit rises from the value "R" when the contacts are closed to a final value "F" in the time period "BUP", reaching full field value at point "FF".

Now let us suppose that we open and close the switch contacts repeatedly. The result will be as shown in Fig.13. The contacts close at the point "C" and open at "O". We get the three high current periods - A-B-C - which result in a mean or average current "MC".

FIG 1.

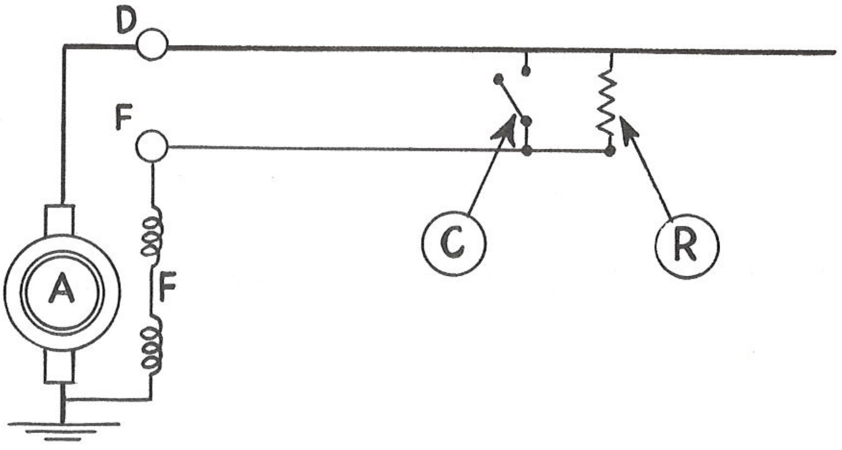


FIG 2.

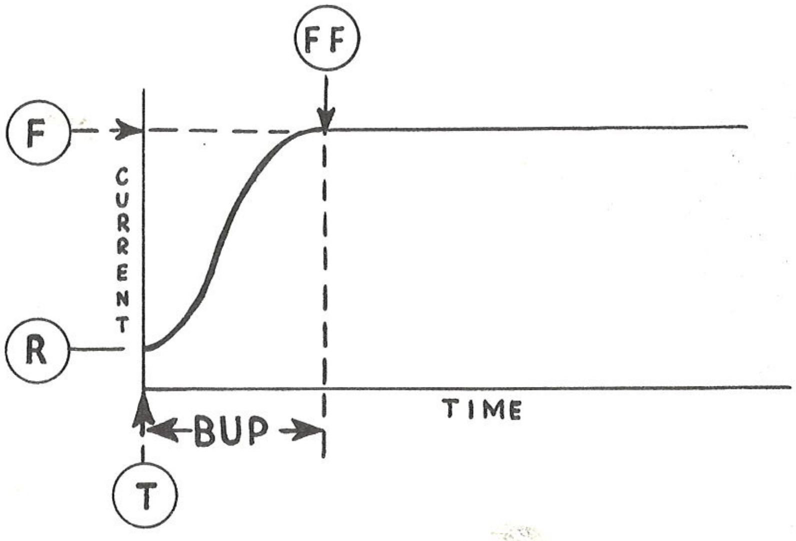


FIG 3.

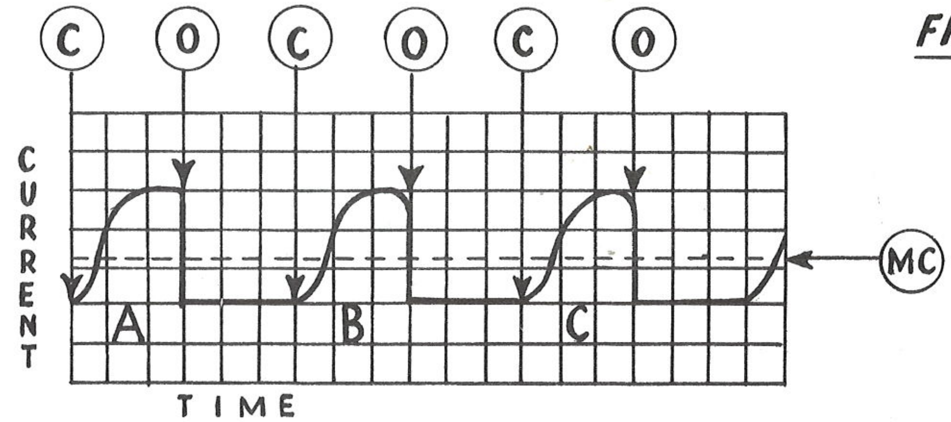
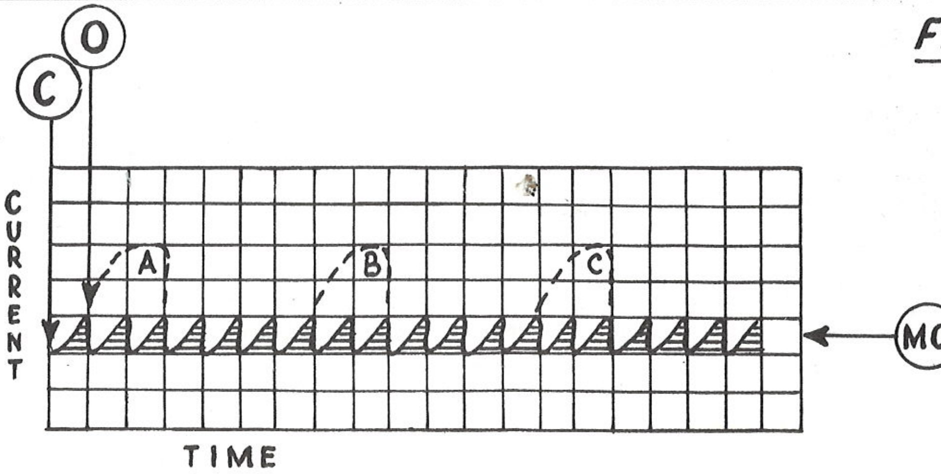


FIG 4.



Now let us suppose that the contacts are opened and closed much more quickly. When the contacts are closed, current starts to rise, but owing to the speed of operating the switch the current is interrupted part way up the curve by opening the contacts. The result is shown in the curve in Fig.4, where the average current MC is reduced because of the higher frequency with which the switch is opened. This means that by increasing the rate of make and break of the switch contacts, the field current can be controlled without altering the value of the field resistance. This is the basic principle on which all voltage regulators operate.

SIMPLE VOLTAGE REGULATOR.

The trembler action described above is used in the basic voltage regulator as illustrated in Fig.5. The regulator consists of an "L" shaped iron frame "IF" carrying an iron core "IC" and an armature plate "AP" hinged at point "H". The outer end of the armature plate is hooked to tension spring "S", the other end of which is anchored to the frame, and the inner end of the plate carries one of a pair of contacts. The second contact is mounted on a fixed bracket at "C"; the pull of the spring holds these contacts together. The core "IC" carries a copper wire coil of fine gauge and many turns so that it will magnetise the core when a small current flows through it. A magnetic field is thereby created in the space between the end of the core and the under side of the armature plate, which become N and S poles of the magnetic field. With current flowing, the iron core will exert a magnetic pull on the plate in opposition to that of the spring and when sufficient voltage is impressed on the winding of core "IC" to produce the necessary current and magnetic strength, the magnetic pull will overcome the spring pull, and the plate will be drawn in, thereby separating the contacts.

Fig.5 also shows the way in which the regulator is connected in the generator field circuit. Three connections branch off the "D" cable from the generator armature. One is connected to the regulator frame; one to the end of the coil winding; one to the field resistance "R". The connection from the "F" terminal is connected to the fixed contact and to the resistance "R".

When the contacts "C" are held closed by the spring, the generator builds up its voltage on a full field. This rising voltage is impressed on the coil winding "W" of the regulator, causing the current and the magnetic field strength to increase, and this magnetic force pulls the armature plate inwards and separates the contacts. The field current of the generator must now flow through the resistance "R" and is thereby reduced. This reduces the generator voltage, weakens the pull on the armature plate and the spring is now able to pull the plate back and cause the contacts to meet again. This cycle of operations is repeated at a steady frequency with the generator speed remaining constant.

If the generator speed is increased, the frequency of the vibrating action of the regulator contacts is also increased, and the higher frequency of contact action holds the generator voltage more closely to the setting determined by the regulator. In this way the regulator maintains the generator voltage at a constant level, although the speed may vary widely from the minimum r.p.m. at which a charging voltage is produced, up to the maximum speed at which the generator is intended to run.

FIG 5.

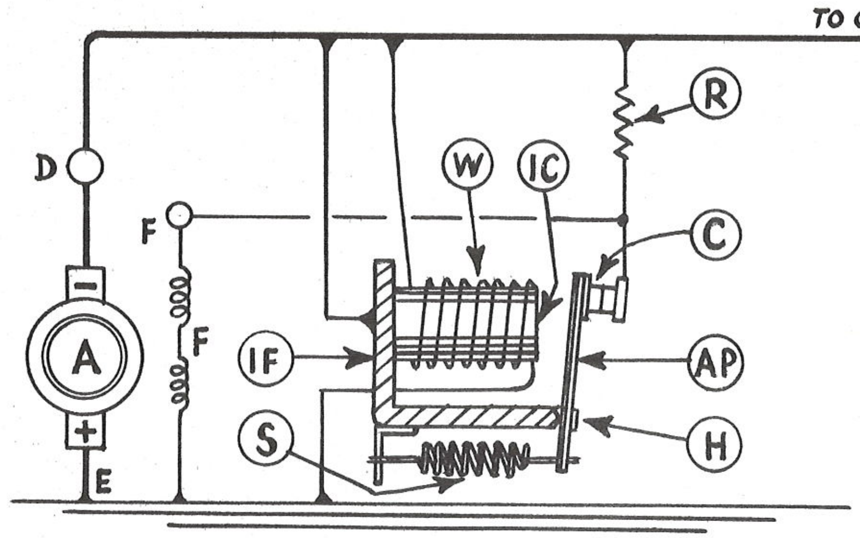

TO CUTOUT
R
D
W
IC
F
C
F
A
−
+
IF
AP
S
H
E

FIG 6.

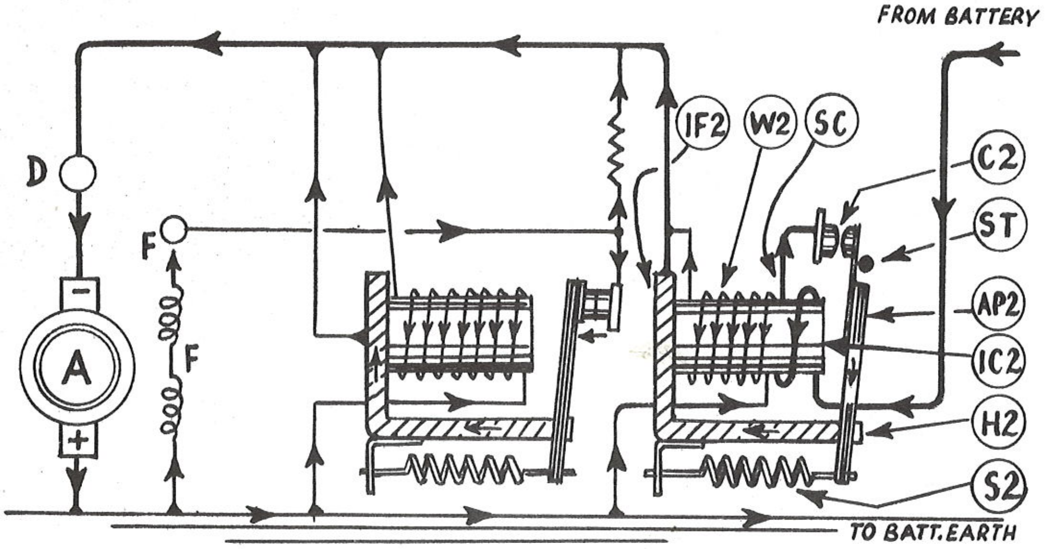
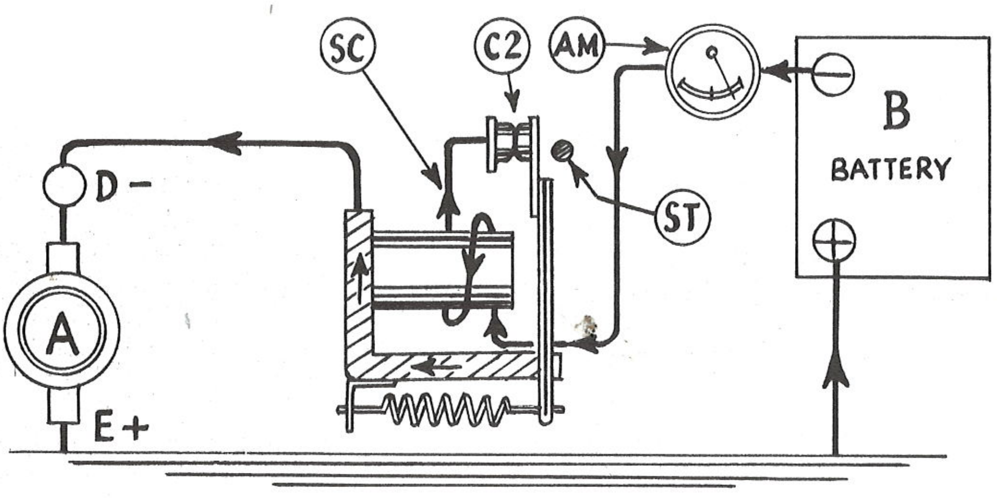

FROM BATTERY
IF2
W2
SC
D
C2
ST
F
AP2
A
−
+
F
IC2
H2
S2
TO BATT.EARTH

FIG 7.


SC
C2
AM
B
BATTERY
D −
ST
A
E +

THE AUTOMATIC CUT-OUT.

Something more than the simple voltage regulator described is needed in the charging circuit. An additional control unit is needed to ensure that the generator is not connected to the battery before its voltage exceeds the voltage of the battery, and is disconnected when its voltage falls below the battery voltage, such as when the engine speed falls to idling.

This control unit is called a "cut-out". The term "relay" is used in the U.S.A. Fig.6 shows the circuit arrangement of Fig.5 with an elementary type of cut-out added. The form of construction is basically similar to that of the regulator and the same symbols indicate the components with the suffix "2". Thus, we have the frame "IF2" with armature plate "AP2" and core "IC2". The armature is held outwards by the spring "S2". The fine wire winding "W2" is similar to that of the voltage regulator and is connected across the generator armature in the same way. Here, however, the similarity ends.

There is a second coil on the cut-out core shown at "SC" this being of a few turns of heavy wire. It will also be noted that the armature plate rests against a stop at "ST" with the contacts open, not closed. One contact is carried on the armature plate; the other on a fixed bracket to which one end of the heavy wire coil is connected.

OPERATION OF CUT-OUT.

The open contacts interrupt the circuit from the generator to the battery. As the generator voltage builds up, this voltage is impressed on the winding "W2" and sets up an increasing magnetic force in the space between the end of the core and the under side of the armature plate. The spring tension is so adjusted that when the generator voltage has reached charging level - approximately 13.5 to 14 volts for 12-volt equipment - the magnetic pull is sufficient to overcome the spring pull and the plate is attracted inwards. The contacts now close and the circuit between the generator and the battery is completed. Current now flows in the direction of the arrows in Fig.7 which shows the entire charging circuit completed with the battery "B" and the vehicle ammeter "AM". The charging current flows round the series coil "SC" on its way back from the battery to the generator and in doing so circulates round the cut-out core in the same direction as the small current flowing in the winding "W2" shown in Fig.6. This means that the charging current will assist the magnetic pull on the armature plate, and will hold the contacts more firmly closed with increasing charging output.

From the instant of closing its contacts, the cut-out serves merely to hold the circuit closed as long as the generator voltage exceeds the battery voltage on charge. When the generator speed declines and its voltage falls and becomes equal to the battery voltage, a state of balance exists and no current flows, although the contacts remain closed. Any further decline of the generator voltage will, however, allow the battery to discharge through the generator in proportion to the difference in the battery and the generator voltages. This discharge current flows round the series coil "SC" in the reverse direction to the charging current and in doing so, produces a reversed magnetic effect. This weakens the pull on the armature plate and when a predetermined reversed current has been reached, the spring pulls the plate outwards, separates the contacts, and opens the circuit. Thus, the cut-out ensures that the main circuit is opened or closed when the correct conditions obtain. It will close the circuit between the generator and battery when the charging voltage is reached, and will open the circuit when the generator voltage has declined below that of the battery to a known extent.

FIG 8.

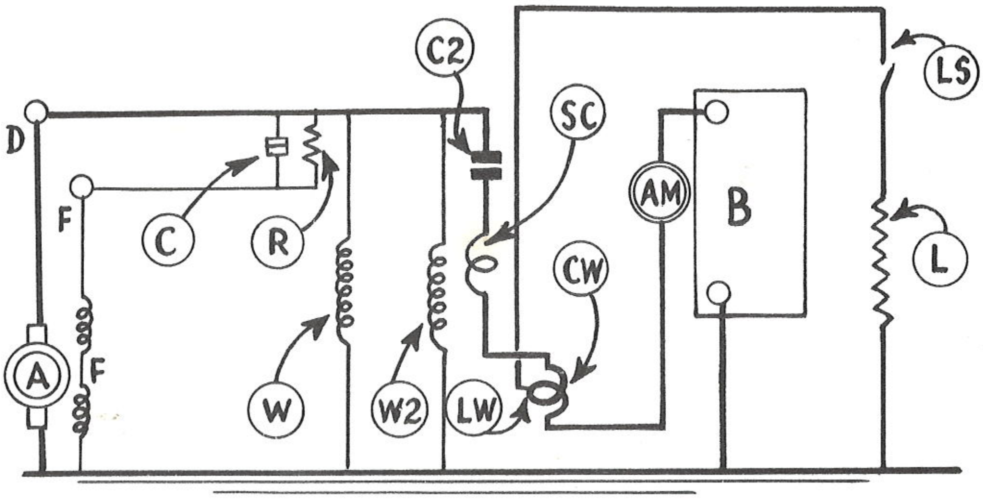
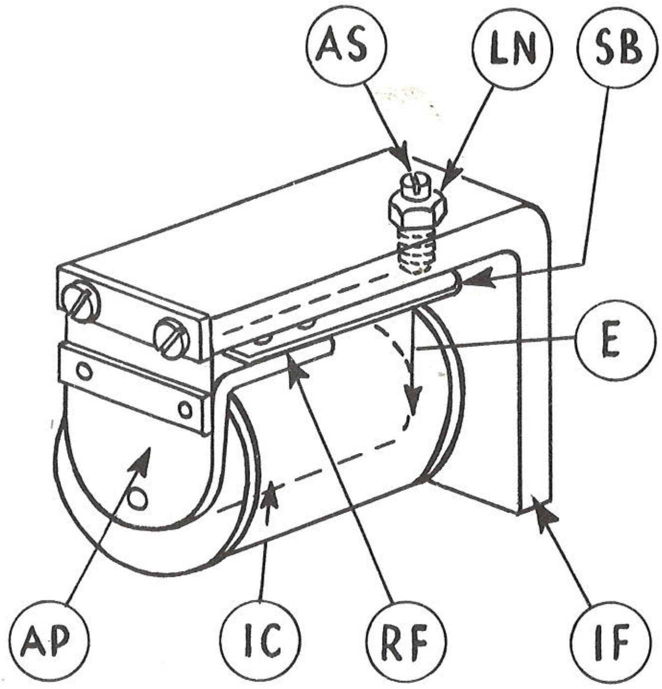

C2
LS
SC
D
F
AM
B
C
R
L
CW
A
F
W
W2
LW

FIG 9.


AS
LN
SB
E
AP
IC
RF
IF

CHARGE AND LOAD CURRENT COMPENSATION.

We have now built up a complete charging circuit with voltage regulation, and can consider the operation of the system in practice, seeing that it is necessary to have some further degree of control. We have already mentioned that the difference of voltage between the generator and the battery enables a charging current to flow. At the commencement of charging, the battery voltage will be approximately 6 volts or 12 volts. If we assume that the voltage regulator has been set to control the generator voltage at a maximum of 16 volts we have a differential of 4 volts for charging the battery. The battery voltage, however, rises progressively whilst the battery is being charged and as the battery comes up on charge, the differential voltage is reduced in proportion. This has the effect of scaling down the charging current until a state of balance is reached.

In practice, however, this state of exact balance - theoretically obtaining when the battery voltage rises to equal the generator voltage of 16 volts - is never obtained. The reason for this is that the reduction of the charging rate as the battery comes up on charge results in a lower level of battery voltage rise, until a point is reached at which the low charging rate fails to cause any further rise in the battery voltage. This usually happens when the battery voltage has risen to about 15 volts, i.e., with a differential of 1 volt. The rate at this voltage will remain steady at about 5-7 amps. in most cases, so long as no load is applied to depress the battery voltage and thereby increase the differential.

When the battery voltage falls abnormally low, due to a state of discharge, or to faulty cells in the battery, or to an excessive load demand, then the differential voltage will be such as to permit a very heavy charging current to flow. If this heavy rate does not immediately bring up the battery voltage, or is being absorbed in supplying a heavy electrical demand, then a serious situation exists which is liable to overload and burn out the generator and regulator unit.

To protect against this possibility British types of regulators are fitted with compensating windings which modify the action of the voltage regulator, so that the regulated level of voltage is automatically reduced when the current exceeds a safe maximum. Fig.8 shows in the form of a diagram how the system operates. The various features will be recognised by their reference letters, which are similar to those used in Figs. 6 and 7. It will be noted, however, that an extra series winding "CW" is wound on the core of the regulator and is connected between the cut-out series coil "SC" and the ammeter - battery line. A tapping from the coil "CW" leads to the switch "LS" and the load circuit "L". The winding "CW" consists of only a few turns of heavy copper strip, wound over the regulator shunt winding "W".

Charging current, flowing round the coil "CW", sets up a magnetic field in the regulator core, which strengthens the magnetic field due to the generator voltage on the shunt winding. The total force due to the two magnetic fields therefore pulls in the armature plate and separates the contacts "C" at a lower voltage. The generator voltage is reduced and the output restricted to a maximum, within the safe limits of the system. If, for example, the battery develops a faulty cell so that its terminal voltage falls from 12 to 10, the additional two volts of differential would cause a considerable increase in the charging rate. The action of the compensating coil carrying this boosted output will, however, pull down the generator voltage and thereby reduce the differential, thus limiting the maximum output in spite of the battery fault.

FIG 10.

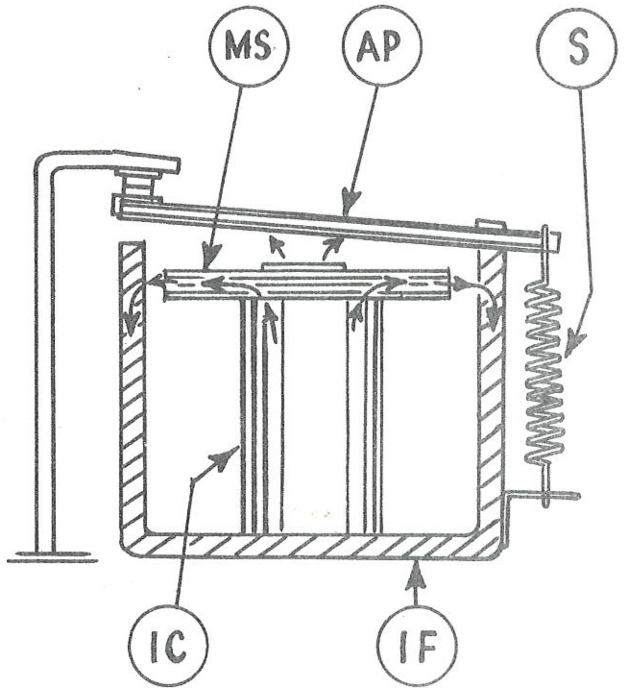


FIG 11.

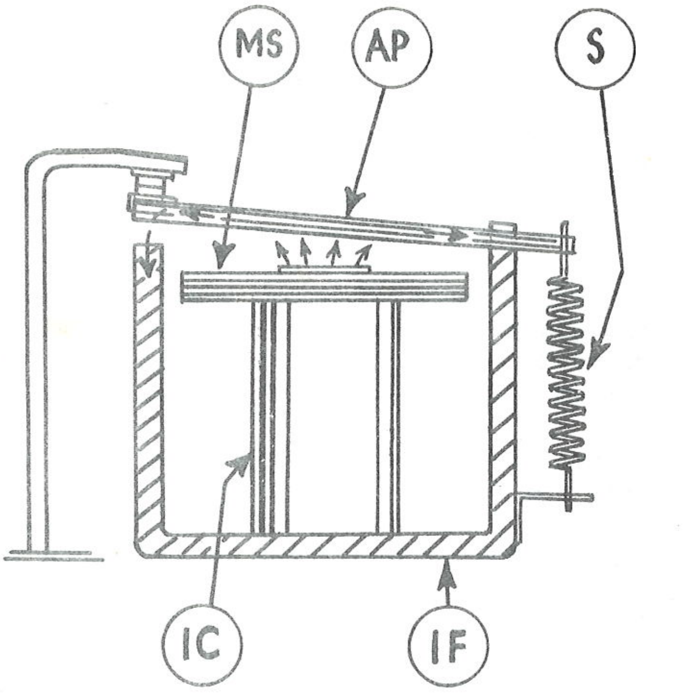
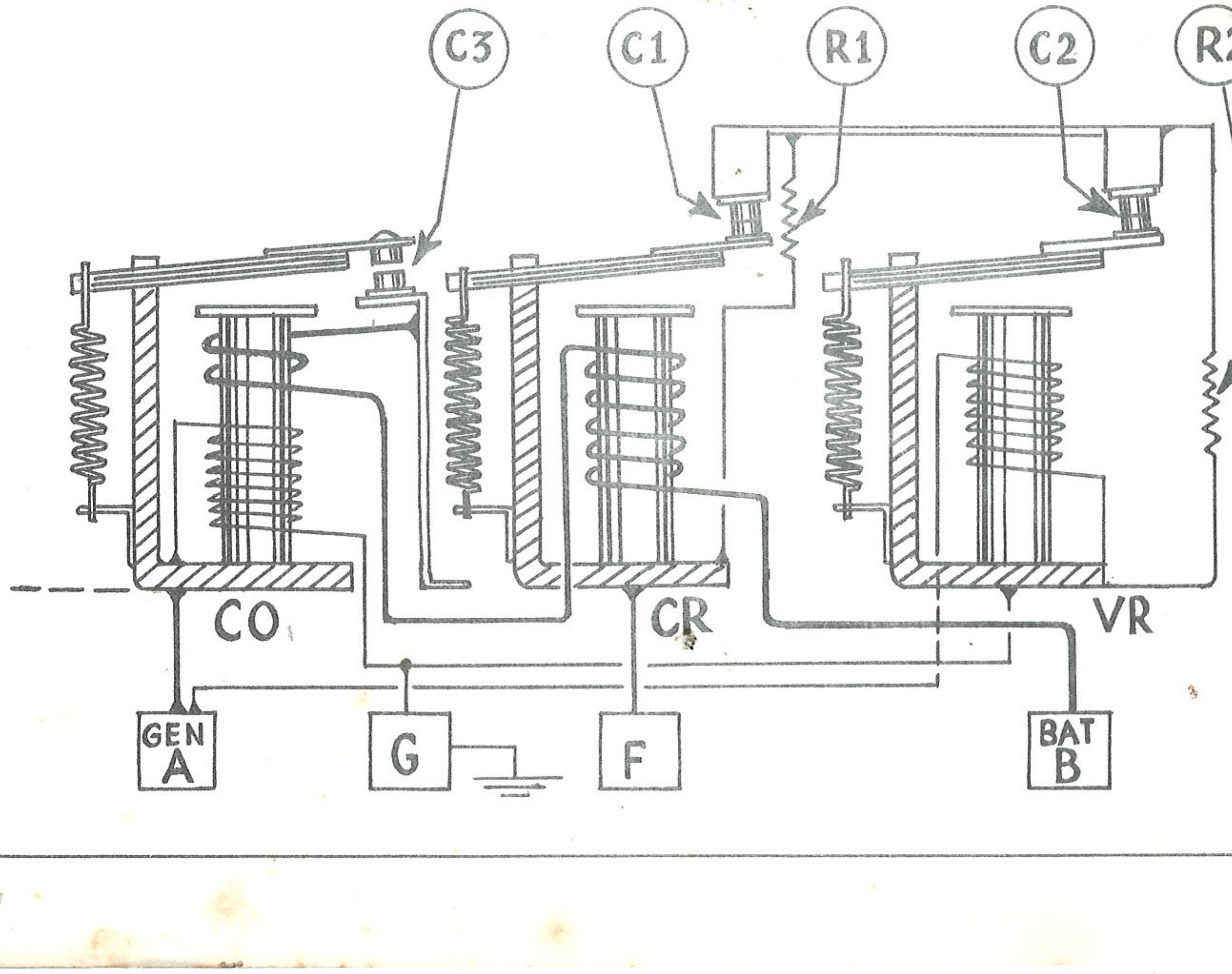


FIG 12.


C3
C1
R1
C2
R2
CO
CR
VR
GEN A
G
F
BAT B

Another condition which might cause excessive output is a heavy load, especially when imposed on a partly discharged battery. All load current, other than the starter current, returns to the battery via the section "LW" of the coil "CW". This also supplements the regulator magnetic field and reduces the output in exactly the same manner as described, so that a short-circuit or other overload cannot damage the system.

TEMPERATURE COMPENSATION.

Under cold conditions a battery can be charged at a higher rate than under hot temperature conditions. Also under cold conditions a generator will give a greater output than when hot. This useful coincidence is put to work in the design of the modern voltage regulators.

The method of determining the voltage setting of the regulator is by adjustment of the armature spring tension. If this tension is so adjusted that it will provide a higher voltage when the system is cold, we can take advantage of the higher generator output available to restore the battery state of charge quickly, for example, after starting on a cold morning. We must, however, also make provision to modify the control to bring the voltage down to normal level when the temperature rises, and also to reduce it still further under very hot conditions.

One method of doing this is to make the regulator armature spring self-compensating so that it will automatically modify its tension according to temperature. The principle used is that of the bi-metal strip, based upon the fact that all metals expand with increasing heat, but some will expand to a greater extent than others in a given temperature rise. In British regulators the spring is in the form of a blade of steel backed by a bi-metallic leaf. This leaf consists of two thin strips of metal of widely different expansion factors welded together. Under cold conditions the leaf lies flat under the steel blade, but increase of temperature causes one metal to expand more than the other. Being welded so that one metal cannot expand in length, the effect is to bend or distort the leaf, causing it to press against the steel blade and effectively reduce its tension. Accordingly, the voltage setting of the regulator is automatically adjusted down, and the generator output is progressively restricted as the temperature rises.

Fig.9 shows the construction of a regulator unit with this form of self-compensating spring. The steel blade and bi-metal strip "SB" which form the spring are riveted at "RF" to the end of the "L" shape armature plate "AP". The free end of the spring bears against the tip of the adjusting screw "AS". Turning the screw clockwise causes its tip to move inwards, thus shifting the anchor point and increasing the static tension of the spring. The voltage setting is thereby adjusted upwards. Turning the screw in the opposite direction has the reverse effect. As the temperature increases the tip of the spring is distorted in the direction of arrow "E", thus slackening off the tension to a proportionate extent, and bringing the voltage level down to suit ambient temperature conditions, with resulting reduced generator output.

MAGNETIC TEMPERATURE COMPENSATION.

An alternative method of automatic correction of the temperature is used in some U.S.A. equipment based on a feature that certain iron-nickel alloys have of changing with heat. Figs 10 and 11 show this assembly where we have a "U"

FIG 13.

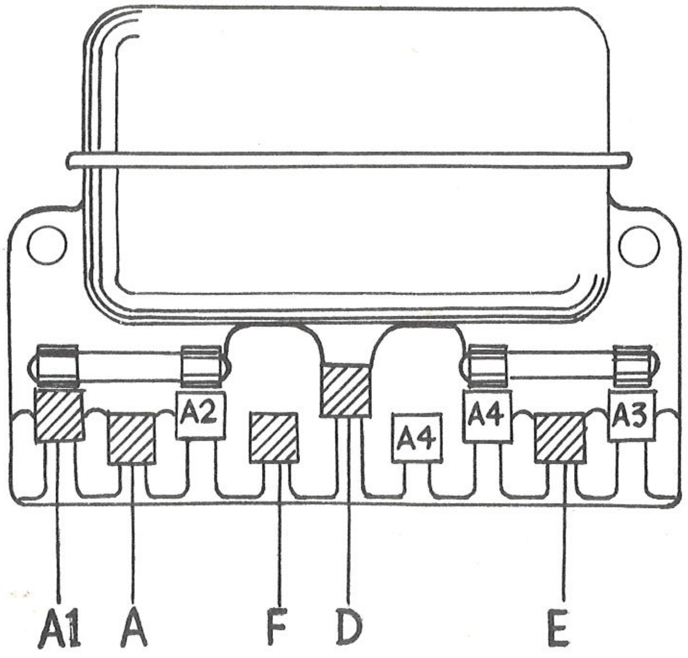

A2
A4
A4
A3
A1
A
F
D
E

FIG 14.

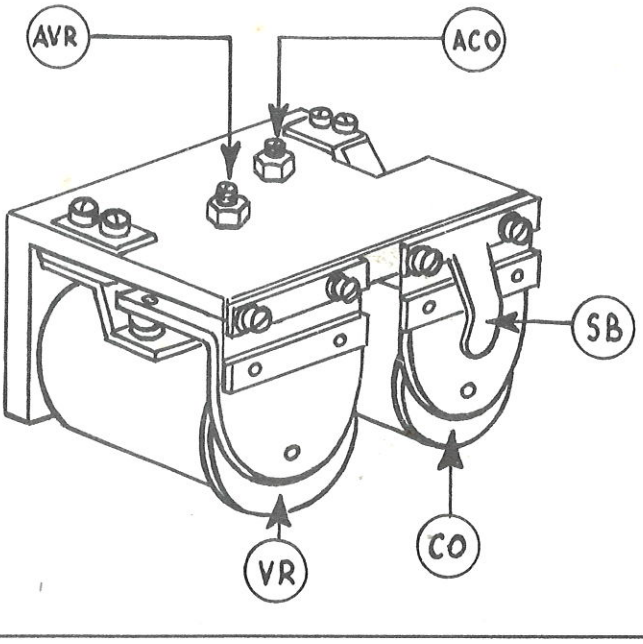
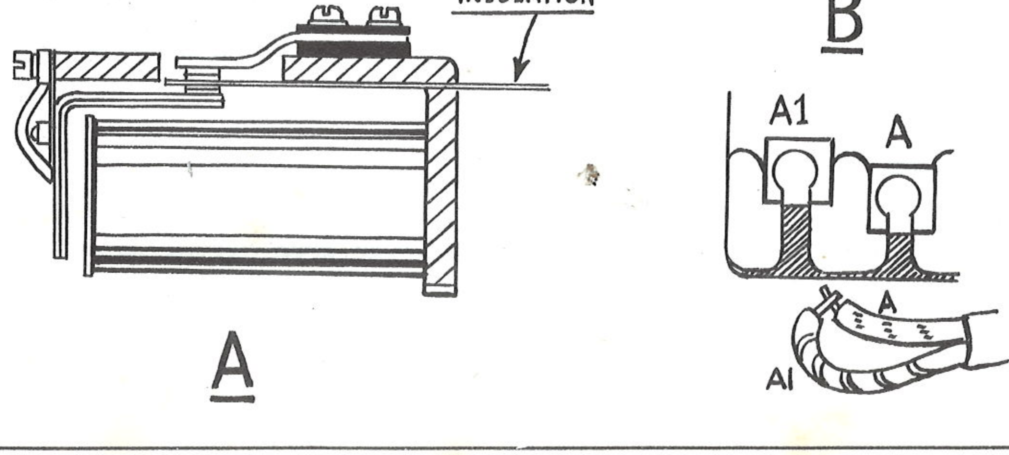

AVR
ACO
SB
VR
CO

FIG 15.


INSULATION
A
B
A1
A
A
A1

shaped frame with a central core, the parts being identified by the same references as in previous diagrams. The top of the core is fitted with a plate "MS" composed of an alloy which has a high magnetic conductivity when cold. This plate clears the sides of the frame by a small air gap and acts as a shunt or leak. Fig.10 shows the path of the magnetic lines of force, by arrows passing through the plate, instead of across the pole gaps to the armature plate. The result is a weakening of the pull on the armature plate when the unit is cold, so that regulated voltage is raised. As the temperature increases the plate "MS" becomes progressively more resistive to magnetic flux and the lines of force are deflected across the pole gap. The pull on the armature is now increased and the voltage level is reduced in proportion.

THE PRINCIPLE OF CURRENT REGULATION.

We now need to consider the operation of the independent current regulator widely used on U.S.A. equipment and now finding its way into British control units. The purpose of the current regulator is to limit the generator output to a safe maximum. It operates, however, on a different basis to that of current compensation in the voltage regulator itself, as previously described.

The construction of the current regulator is basically similar to the voltage regulator, but the core carries a single heavy wire winding of a few turns, through which passes the main charging output from the generator.

Fig.12 shows the internal circuit layout of a typical "three-unit" control box as used with U.S.A. type generators in which the field circuit is completed to "Earth" (or "Ground") via the control unit. Unit "VR" is the voltage regulator, "CR" the current regulator, and "CO" the cut-out. The contacts "C1" and "C2" of the two regulators are normally held closed by spring tension while the cut-out contacts "C3" are held open by the spring as previously explained.

It is desirable to trace the three circuits contained in this control unit so that the operation of the units as a set will be properly understood.

(a) Firstly, the field path must be completed to Earth. Starting at terminal "F" the circuit leads to the frame of "CR", contacts "C1". and "C2", the frame of "VR", and the common connection to "G" (ground).

(b) The generator voltage at terminal "A" (armature) is applied to the light wire winding of "CO" and "VR" with a common return to ground, and this voltage is present at the frame of "CO".

(c) At the correct voltage the cut-out closes contacts "C3", when charging current flows round the heavy winding of "CO", the winding of "CR" and continues to the battery via terminal "B".

Assuming that the generator is running at charging speed on a full field with the cut-out closed and the charging current flowing, the voltage regulator first takes control. The contacts "C2" start to vibrate and field current is deflected through the resistor "R2", thereby holding the voltage at the correct level.

The current regulator takes over control when conditions get outside the range of the voltage regulator. This can happen when a heavy load or faulty insulation pulls down the battery voltage. This will result in a heavy charging

FIG 16.

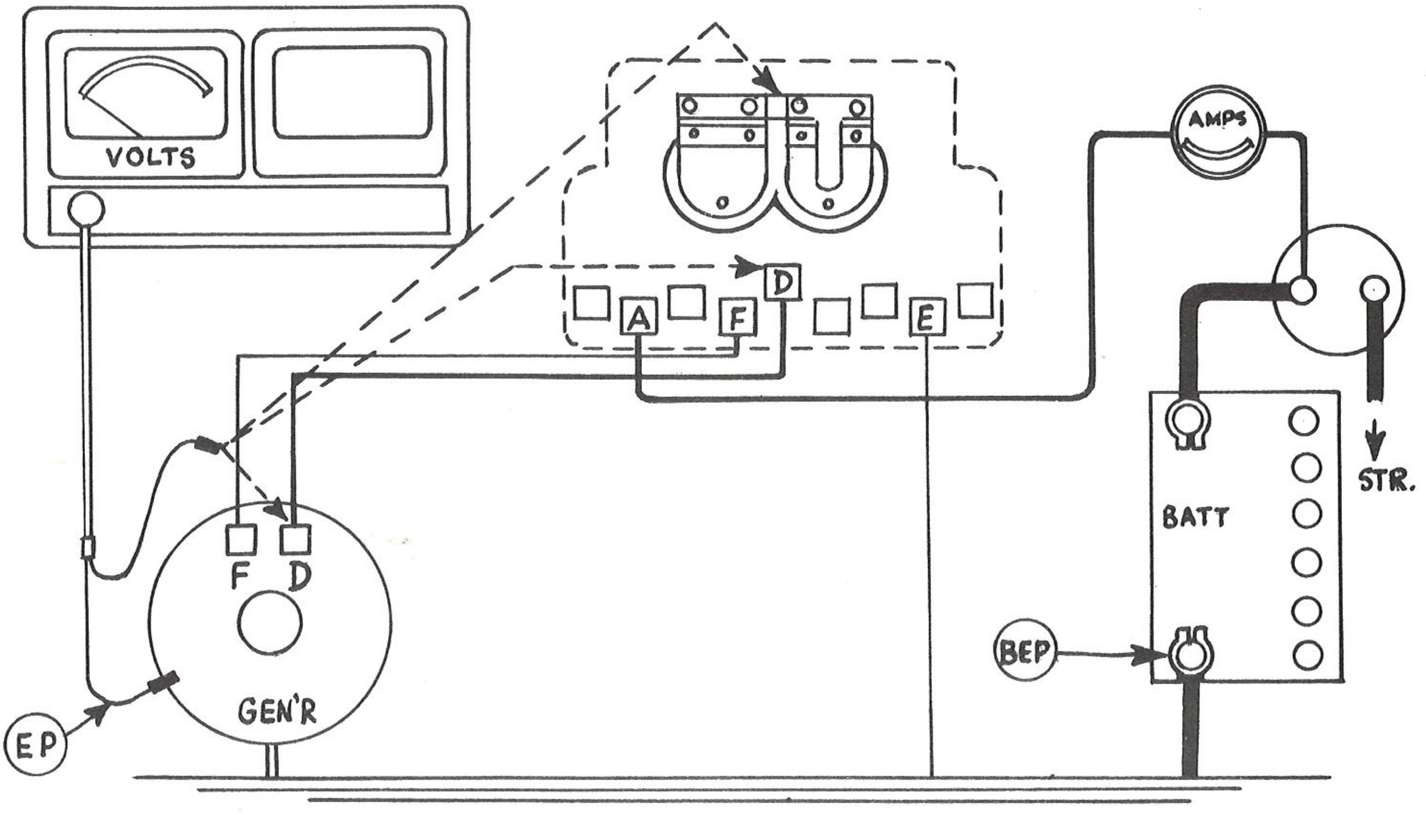
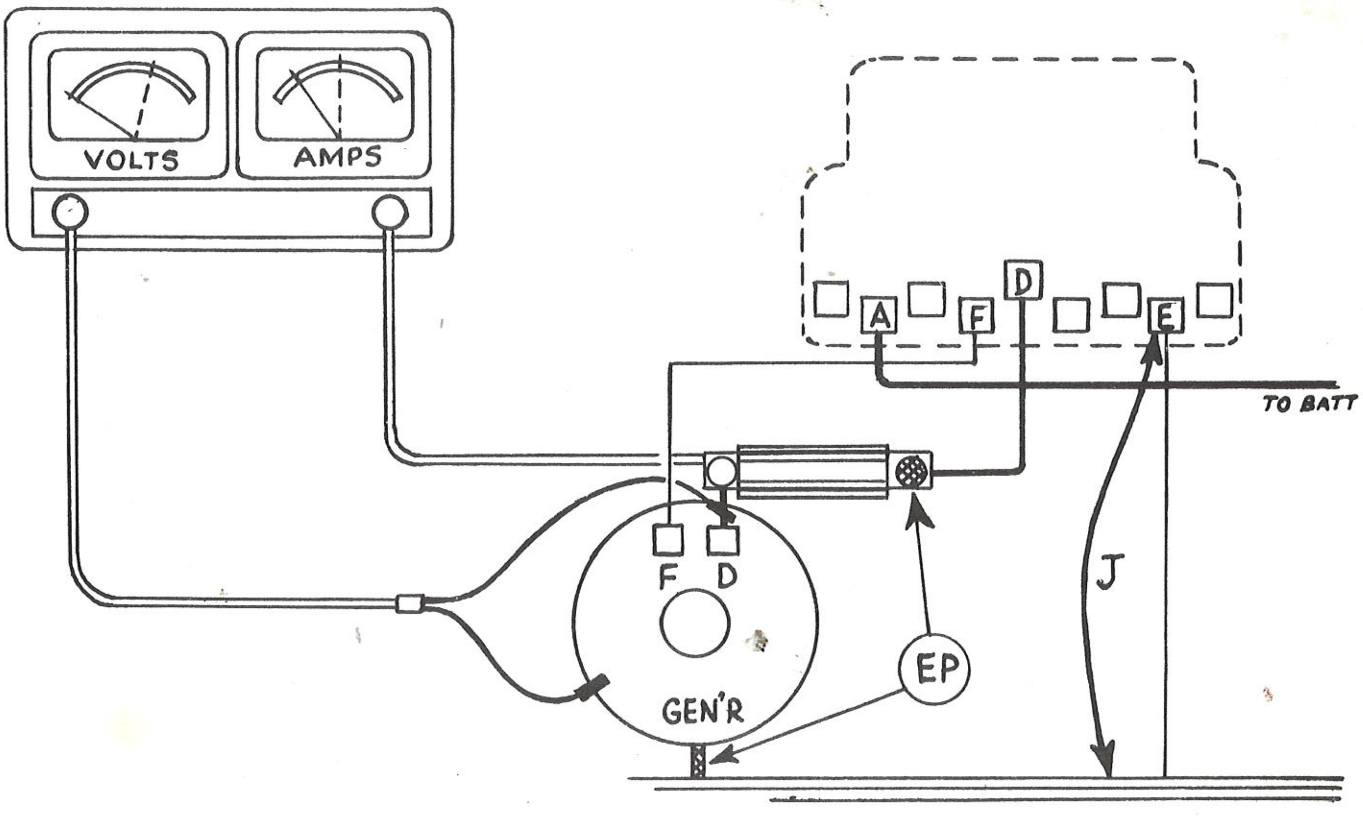

VOLTS
D
A
F
E
AMPS
F
D
GEN'R
EP
STR.
BATT
BEP

FIG 17.


VOLTS
AMPS
D
A
F
E
TO BATT
F
D
GEN'R
EP
J

rate which reduces the generator voltage below the point of voltage regulation. The contacts "C2" will now remain closed but the strong magnetic field produced in the core of "CR" will start a vibratory action of contacts "C1", deflecting the field current through resistor "R1". This action reduces the charging rate and holds it to the safe limits for which the system is designed.

In a unit of the type described, either a voltage regulator or the current regulator operate - they do not operate together. Under all normal conditions the voltage regulator effects control of the generator voltage, but in the event of a heavy charging rate for any reason, the current regulator takes over the controls and keeps the maximum charging rate within acceptable limits.

PRINCIPLES OF REGULATOR ADJUSTMENT.

The initial factory settings of a control unit must not be altered without clear avidence that an alteration is needed. The factors which determine the operation of the unit are quite simple, and comprise -

(1) The tension of the armature plate spring. Manufacturers' data will show how the spring tension is adjusted, whether by screw, cam plate, or setting of the fixed anchor point. In every case the spring tension is increased to raise the voltage or current response and is reduced to lower the voltage or current response.

(2) The air gap between the top of the core and the underside of the armature plate must be accurately set. This can be altered by adjusting the position of the outer contact regulators or the stop pin of the cut-out.

(3) The gap between the contacts must be correctly adjusted and this is carried out by altering the air gap.

Details for the adjustment of all the above factors are included in the Manufacturer's service data. Normal service usage, however, generally requires only the correction of the spring tension to ensure that the proper voltage and current settings are maintained, always provided that the contact surfaces do not need reconditioning. The manufacturer's recommendations must always be accurately followed to ensure good performance of the regulator.

REGULATOR TEST PROCEDURE.

Regulator tests form a part of the complete diagnosis schedule which is given in the next lesson. General instructions only are given here because various manufacturers supply detailed test data for their own equipment.

TESTING LUCAS REGULATORS.

(a) Identity of Terminals. All Lucas regulators are associated with an automatic cut-out in a complete unit called the Control Box. The Control Box has terminals marked by letters which show their positions in the circuit layout. Fig.13 illustrates the Lucas RF.95 Control Box. The terminals concerned with the regulator and cut-out are marked in heavy lettering. The remainder are accessory feed points via the fuses and are

FIG 18.

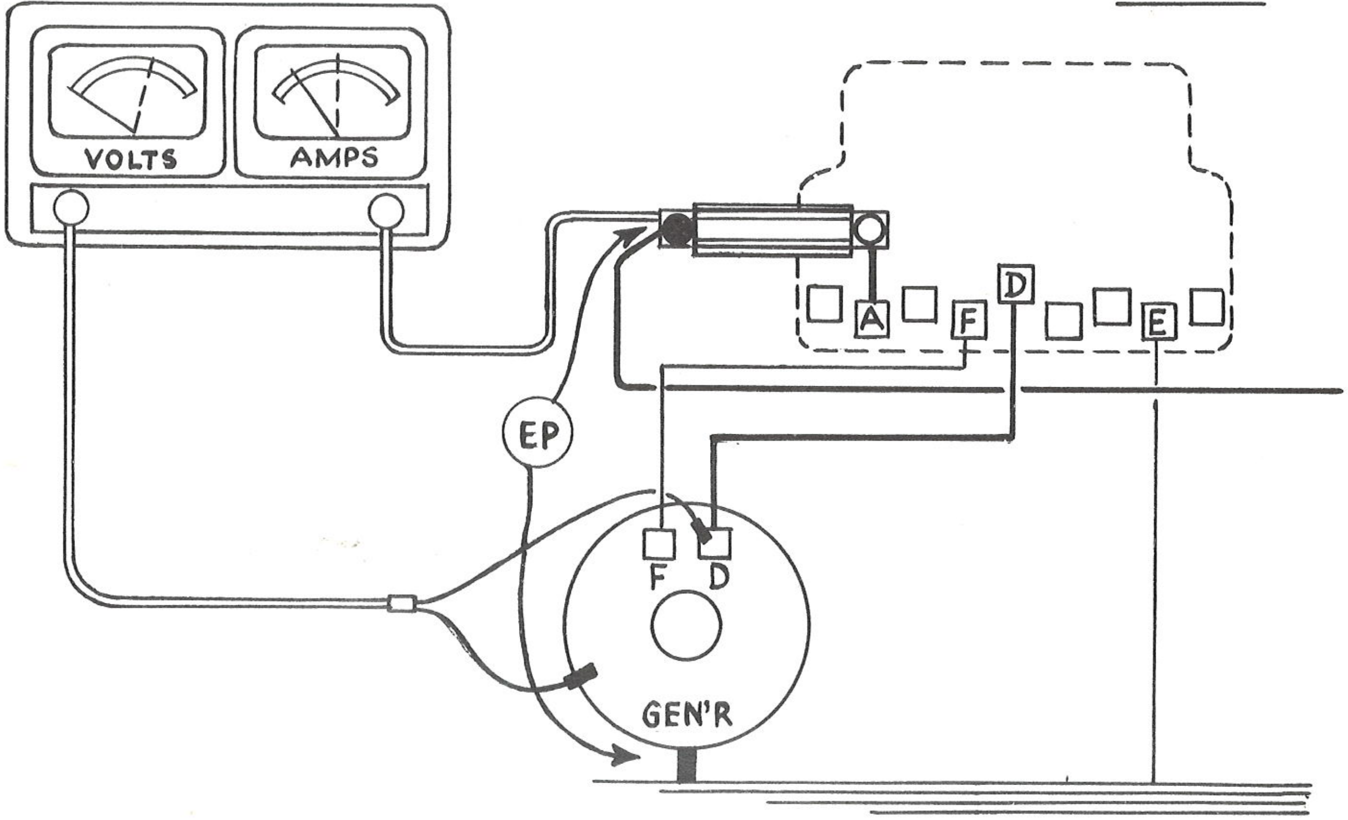

VOLTS
AMPS
A
F
D
E
EP
F
D
GEN'R

FIG 19.

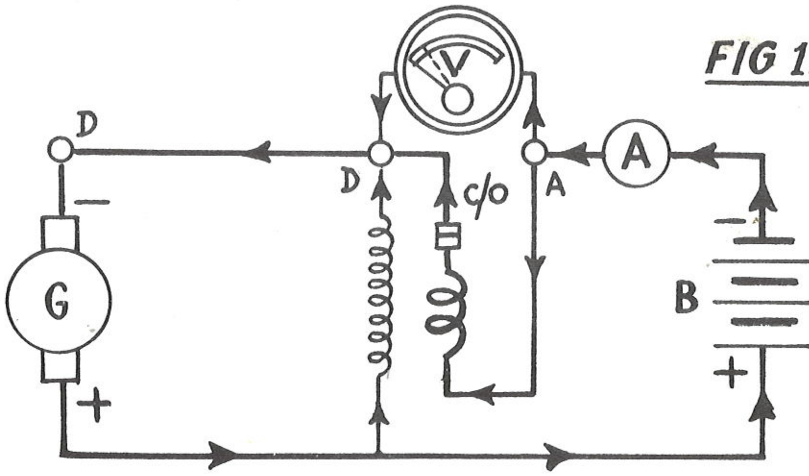
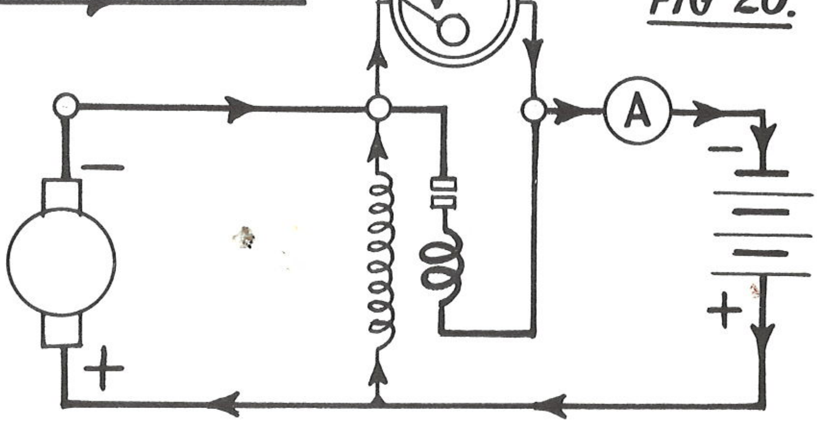


FIG 20.



located in the control box for convenience in vehicle wiring. The same letters identify the same points in any other Lucas control box and we can remember them as signifying -

"D"	...	generator armature.
"F"	...	generator field.
"E"	...	earth connection.
"A"	...	ammeter cable to the meter.
"A1"	...	feed point for load circuits.

(b) Inspection. Before making any test connections, remove the control box cover and examine the regulator unit carefully, noting any evidence of overheating of winding. See that no screws or parts are loose, soldered connections melted, wires detached or other obvious faults exist. Check that the frame is secure on the moulded base, but avoid touching the cut-out armature. Check the wiring connections to the terminal.

Fig.14 shows the features by which you will recognise the cut-out "CO" and the regulator "VR" both of which are mounted on a common frame. The cut-out armature plate bears outwards against the stop "SB". - there is no stop bracket on the regulator armature plate. Adjusting screws are located over the respective cores. The regulator screw "AVR" is further from the base than the cut-out screw "ACO". Each is locked by a 4BA nut.

(c) Testing Open Circuit Voltage. A test of regulator voltage is made in Lucas equipment with the charging circuit held open. This can be achieved by inserting a slip of dry paper between the open cut-out contacts so that they cannot meet when the armature plate pulls in; this is shown in Fig.15. An alternative method is also shown in Fig. 15b, namely, by detaching the cables from terminals "A" and "A1" and joining these cables together. This serves the dual purpose of opening the connection between the cut-out and the battery, and also establishes a battery feed to the ignition system, so that the engine can be run.

Connect a moving coil voltmeter across the main generator terminal, making sure that the voltmeter is switched to the correct range - 0-10 volts for 6-volt equipment and 0-20 volts for 12-volt equipment. If the battery positive terminal of the vehicle is connected to earth, connect the positive voltmeter lead to the car frame and the other lead to the generator or regulator "D" terminal. Fig.16 illustrates the connections. The voltmeter terminal connection can be made at any of the three points illustrated in the diagram.

Start the engine and increase the speed gradually, when the voltage reading should rise until it reaches approximately 8 volts for 6-volt equipment or 16 volts for 12-volt equipment, at which point the reading will stabilise and remain constant over a wide range of speed above this minimum. Check the temperature of the air surrounding the regulator by placing a thermometer bulb close to the unit for a few minutes, when the voltmeter reading can be compared with the manufacturer's figure for the temperature.

(d) Checking Cut-out Closing Voltage. Fig.17 shows the connections for testing the closing voltage of the cut-out. The paper insulator is removed from the contacts or the cables reconnected if detached. A test ammeter should be connected in series as shown in Fig.17. Start the engine and gradually increase the speed, watching the rise of generator volts. The voltmeter will show a momentary flicker of its pointer at the instant the cut-out closes, and the voltage reading at this point should be carefully noted.

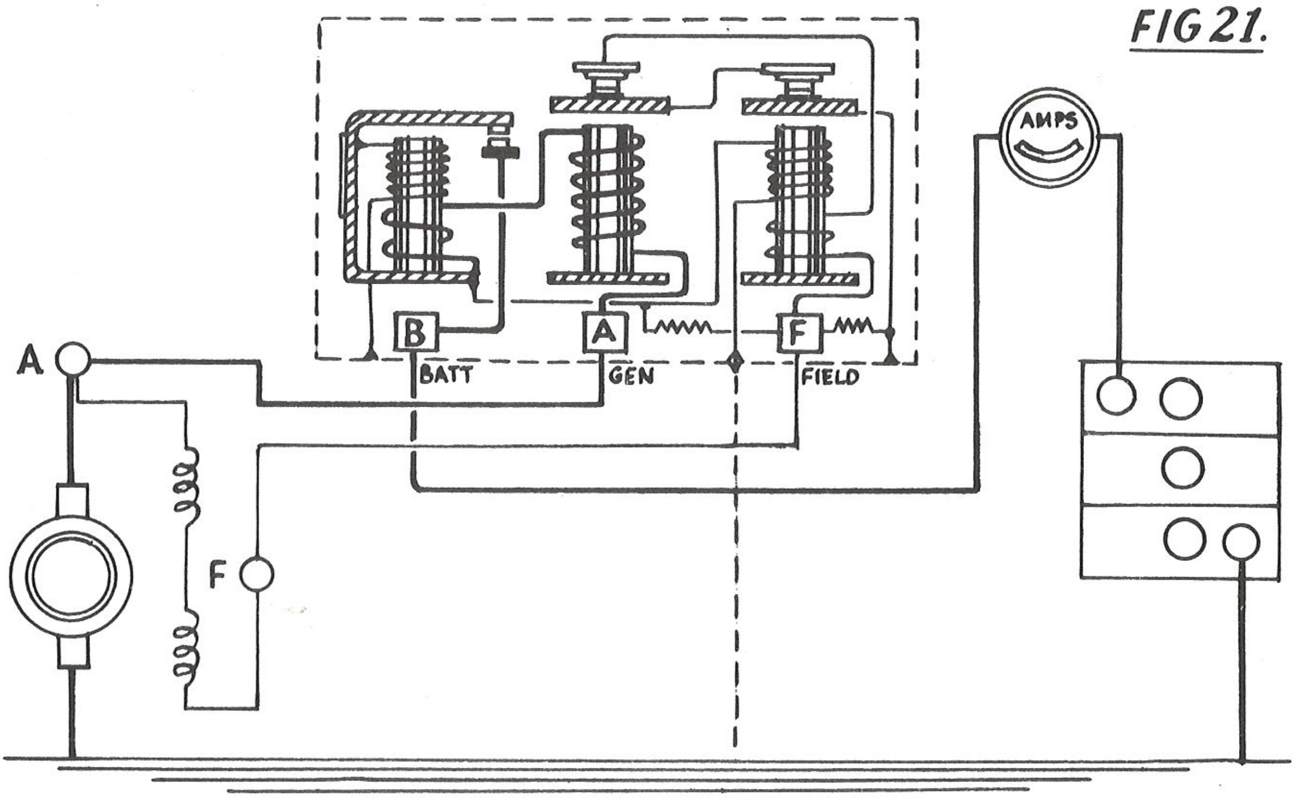

A
F
B
BATT
A
GEN
F
FIELD
AMPS

FIG 21.

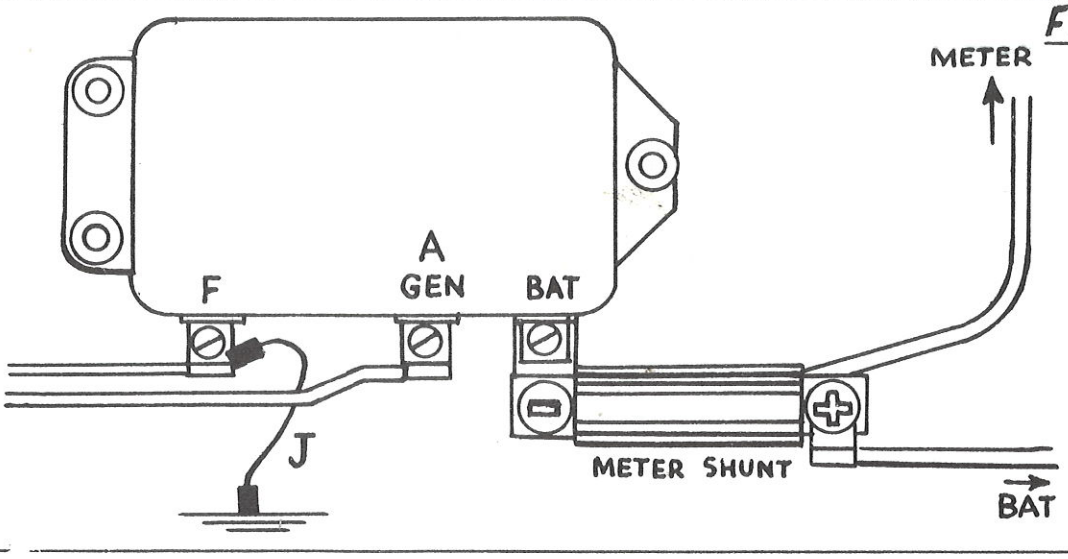

METER
A
GEN
F
BAT
J
METER SHUNT
BAT

FIG 22.

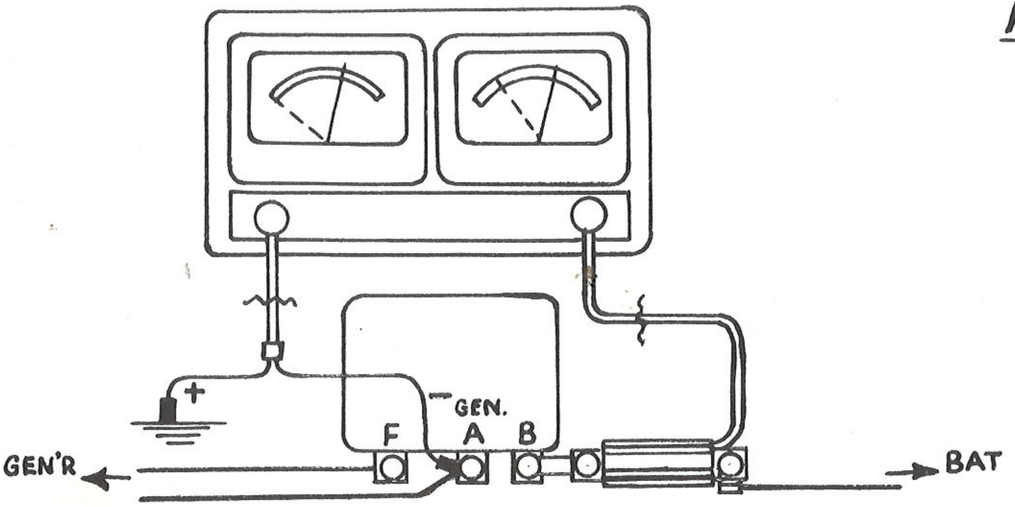

+
GEN.
F
A
B
GEN'R
BAT

FIG 23.

Compare the reading with the manufacturer's data. For most Lucas C.V.C. cut-outs the closing voltage is 6.3 to 6.7 volts for 6-volt equipment or 12.7 to 13.3 volts for 12-volt equipment. If the reading is higher it indicates that the generator is cutting in at a high voltage. This can be corrected by adjusting the spring tension, but no adjustment should be attempted until the earth line has been tested as follows:-

(e) Testing Regulator Earth. The connection from the Control Box "E" terminal to the vehicle earth is part of the return path of the shunt winding of the cut-out and regulator. Any undue resistance in this line will reduce the current and weaken the magnetic field in both units. To test the regulator earth, connect a jumper lead as shown at "J" in Fig.17. If the first test of the cut-out gave a high voltage reading which becomes normal when the test is made with the jumper connected, this shows that excessive earth resistance is causing the high voltage.

(f) Testing Output Response. With a test ammeter connected as shown in Fig.17 the output of the generator is registered. To check the response of the regulator, stop the engine, and switch on all lighting load for a few minutes, and also operate the starter with the ignition switched off, or with the "CB" terminal of the distributor connected to earth. This has the effect of depressing the battery voltage and when the engine is re-started and run at about the same speed as before, there should be an increase in the generator output. The reason for this is that the charging rate to a battery in a low state of charge should be higher than during normal operation.

(g) Output Response to Temperature. To check the output response to temperature, run the engine at a constant nominal speed, and cool the regulator with a gentle air stream by means of a blow-gun. When this is done the output should show a tendency to increase slightly. This test can also be made while running the regulator on open circuit when the response will be shown by an increase in the regulated voltage.

(h) Testing Cut-out Reverse Amps. When the above test is made the ammeter connected as in Fig.17 will also indicate the field current. It will show 1 to 2 amperes when the engine is idling and this figure must be noted. To test the reverse current the engine is run up to charging speed to close the cut-out and then gradually slowed down, noting the reading at the instant the cut-out opens. If the reading declines to say, 2 amperes on the discharge side of zero before flicking back to 1½ amperes on the charge side, then we have an actual reverse current of 3½ amperes.

Fig.18 shows an alternative method of connecting the ammeter in series with with the "A" line to the battery. The instrument will now read zero when the cut-out is opened and the reverse current is indicated by the deflection to the left of zero before the contacts separate. Care must be taken to avoid switching on any load when the ammeter is connected in this manner.

(i) Volt Drop on Charging Circuit. This is the final stage of a complete diagnosis of the charging circuit. The procedure is described in Lesson No.6 which deals with volt-drop tests.

A special note should be made of voltmeter connections at this point - especially when connected across the cut-out.

FIG 24.

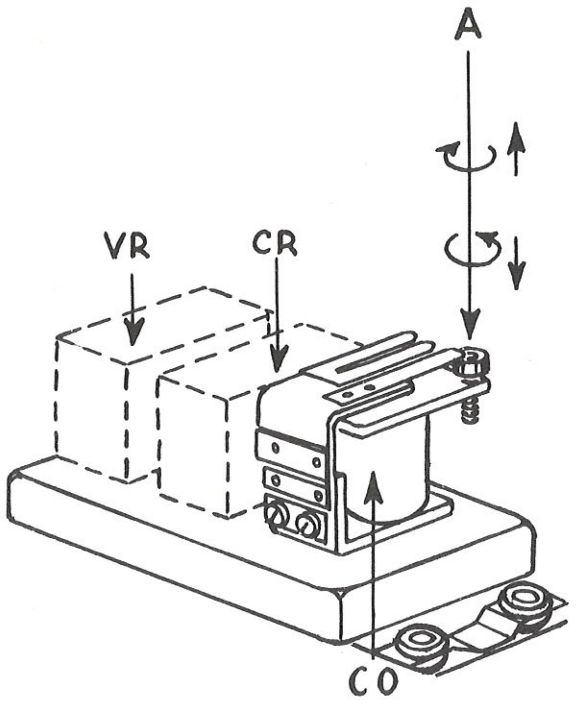


FIG 25.

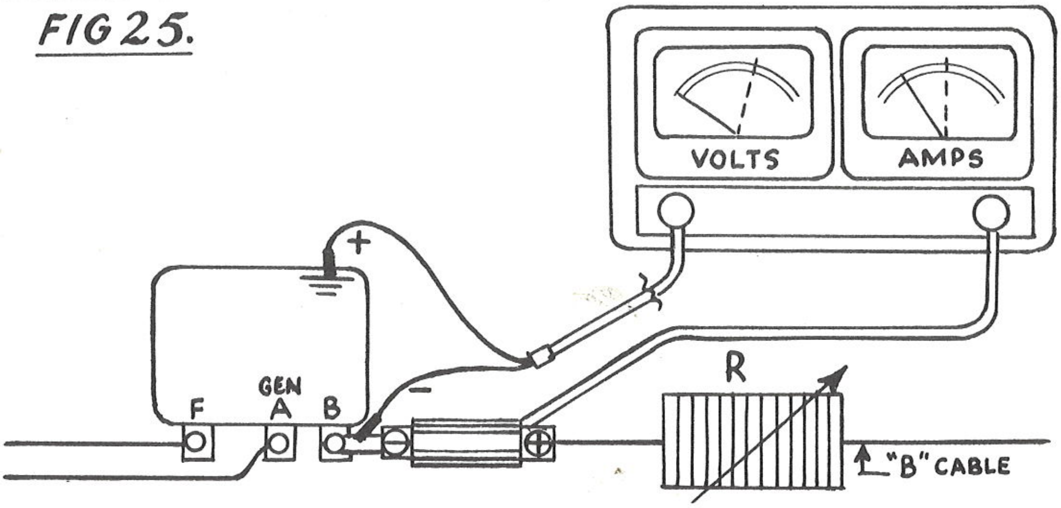

VOLTS
AMPS
+
−
GEN
F
A
B
R
"B" CABLE

FIG 26.

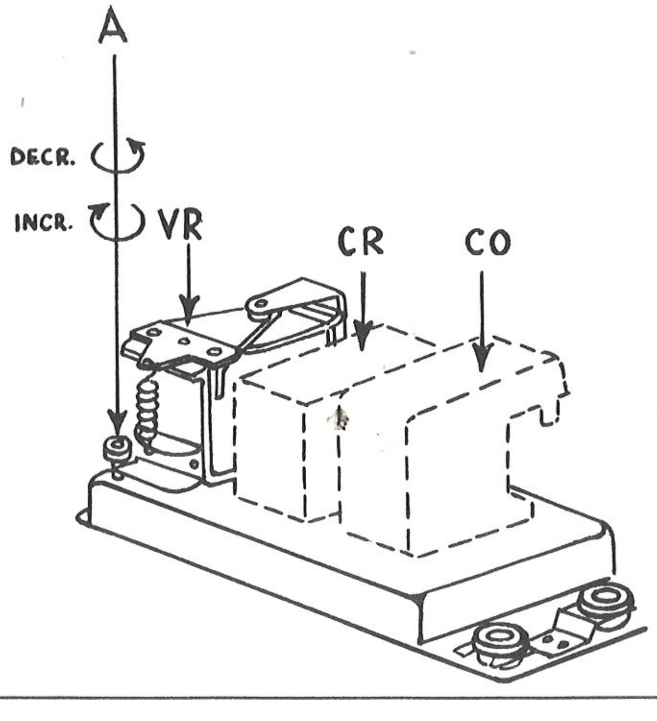

A
DECR.
INCR.
VR
CR
CO

Fig.19 shows a generator "G" connected through the cut-out "CO" to the battery "B". The cut-out is closed, charging current flowing in the direction shown by arrows, and the voltmeter "V" will register merely the volt-drop across the contacts and series winding.
Fig.20 shows the same circuit with the cut-out open, the generator voltage being zero, or below that of the battery. The arrows show that current flow - now deflected through the voltmeter - is reversed. As the voltmeter is reading to the left of zero, it should not be connected across "D" and "A" terminals except when charging current is flowing, and must be disconnected before the cut-out opens

TESTING DELCO-REMY VOLTAGE AND CURRENT REGULATORS.

The same basic methods of test and diagnosis as previously described, are applied in the case of U.S.A. regulators, although the test connections and operations differ from those recommended for Lucas equipment. A Delco-Remy regulator of the 1118300 series, as used on Pontiac cars, is taken as an example. The maker's service data should be consulted for details of corrective treatment.

Fig.21 shows the internal circuit layout of this regulator unit. It will be noted that there are some differences from the basic three-unit box discussed earlier. The cut-out shunt winding and that of the voltage regulator are connected from the point of junction of the series coil to the cut-out frame, and the voltage regulator carries an additional series winding connected in the field circuit.

As with all regulator units having metal covers, such as the Delco we are now discussing, the "BATT" cables should be disconnected and placed clear of earth metal and the cover then removed.

The regulator windings, contacts, connections, fixing screws, should all be carefully checked. The polarity of the unit should also be noted. These regulators are designed for a specified earth polarity and the contacts will suffer if used in reverse polarity. Refit cover and battery cable. The engine must be run at about 1500 R.P.M. for 15 minutes to warm up the units and stabilise voltage setting. All tests must be made with the cover in place.

The first test is a check of regulator contact oxydisation for which purpose a test ammeter is connected in series with the "BATT" terminal and the cable from which it has been detached as shown in Fig.22. The polarity of the ammeter leads is shown for a system with a positive earth. Reverse the leads where the negative is earthed. Run the engine at a nominal speed to produce an output of 5 amperes and then connect a jumper lead to terminal "F" and Earth as shown at "J" in Fig.22. Observe the result on the ammeter reading. If the reading increase is more than 2 amps. the regulator contacts are oxydised and need servicing.

Cut-out Closing Voltage.

Fig.23 shows the connections for testing the cut-out closing voltage of the Delco-Remy regulator in question. The engine is speeded up gradually, when the reading should flicker and become steady at a point between 5.9 and 6.8 volts. The cut-out can be adjusted by turning the cut-out spring adjustment screw shown in Fig.24. The ammeter lead should be disconnected from the battery "BATT" temporarily, whilst the adjustments are being made to prevent accidental closing. Turn the screw slightly clockwise to increase the closing voltage or anti-clockwise to reduce the

FIG 27.

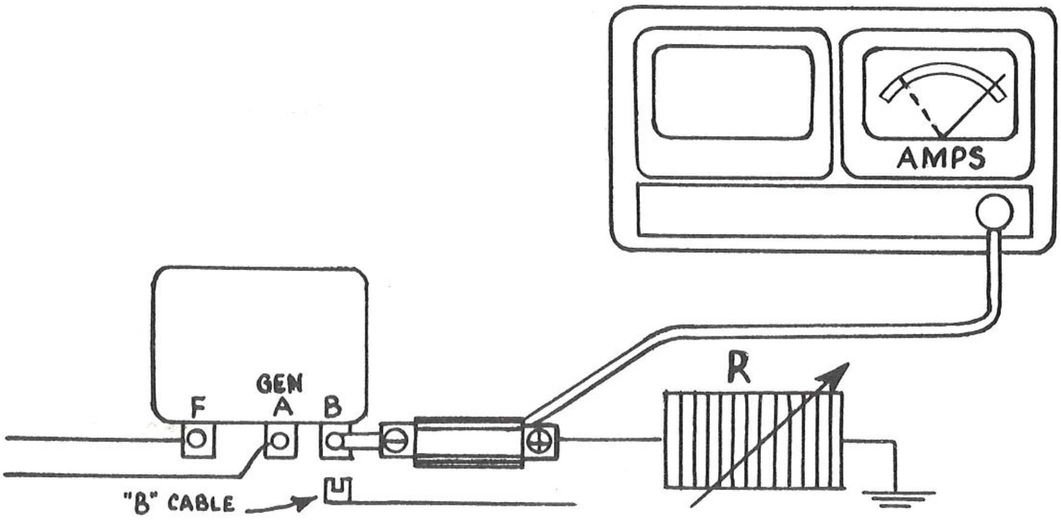
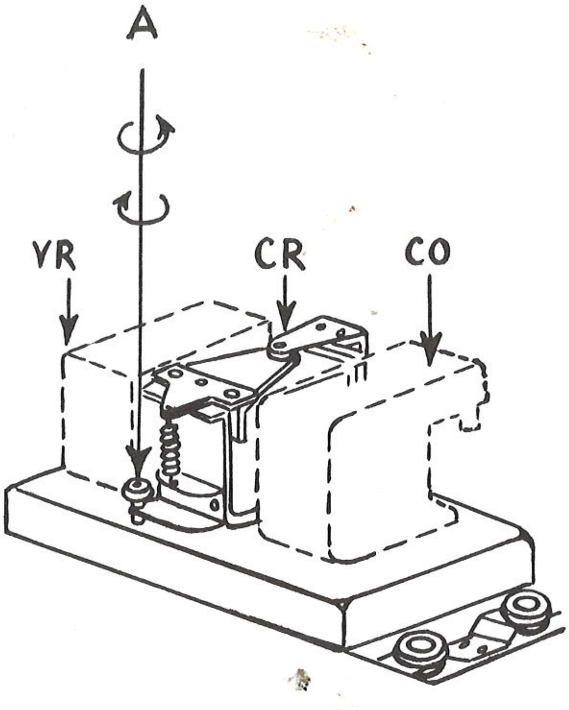

AMPS
R
GEN
F
A
B
"B" CABLE

FIG 28.



voltage. Reconnect the ammeter and repeat the test. A final setting should be made at 6.4 volts.
Note that the screw is left hand threaded.

Testing Voltage Regulator.

With the Delco Remy regulator in question, as in the vast majority of U.S.A. regulators, the voltage regulation must be tested under a stated load and not - as in the case of Lucas equipment - on open circuit. Fig.25 shows the connections with a variable load resistance "R" connected in series with the ammeter and the "B" cable. The resistance is adjusted and engine speed set to produce a charging rate of 9-10 amperes at which the voltage reading should be 7.0 to 7.7 volts. The amount of resistance in the circuit depends upon the state of charge of the battery - the average is 0.75 ohms. If the voltage of the regulator is outside the above limits, the adjustment should be corrected as shown in Fig.26, turning the screw clockwise to increase the voltage or anti-clockwise to reduce. The adjustments should be set to a reading of 7.4 volts.

Testing Current Regulator.

Fig.27 shows the connections for testing the current regulator with a test ammeter and rheostat connected in series and attached to the "B" terminal and earth after the "B" cable has been removed. The engine speed is increased to approximately 2000 R.P.M., and the resistance adjusted to increase the generator output to a maximum. The ammeter reading should rise to 32 - 40 amperes and this output should be held steady when the speed is further increased. If the output is outside these limits the current regulator should be adjusted as shown in Fig.28, turning the screw clockwise to increase or anti-clockwise to reduce. Should adjustment be necessary the output should be set at a maximum of 36 amps.

Checking Regulator Uniformity.

At the conclusion of each test the engine speed should be reduced to idling and then increased to bring the regulator into action again several times to prove that the unit will operate with accuracy at the setting determined.

Polarising the Generator.

In the case of the equipment in question, special emphasis is laid on the necessity of polarising the generator at the conclusion of regulator tests or adjustments. This is done with the engine switched off, by momentarily flashing across the "G" and "B" terminals with a jumper lead after all cables have been reconnected. The result is to deflect battery current through the generator armature and field circuit to ensure that the residual polarity in the field pole shoes is correct. Special attention should also be given to the volt-drop tests of connections between generator carcase, regulator frame and earth, all of which are described in detail in Lesson No.6. Resistance in these parts of the charging system may result in de-polarising the generator and consequent damage to the cut-out or regulator contacts.

SUMMARY.

The information given in this Lesson is largely concerned with the principles of operation of voltage regulators because it is essential that every student should clearly understand why the various tests and adjustments are made. The principle points to be remembered are as follows:-

(1) Examine the regulator carefully and identify the type and operation.

(2) Check with the maker's data for the vehicle and see that the unit fitted is of the correct voltage and polarity where specified.

(3) Locate the terminals and wiring connections.

(4) See that the regulator is adequately warmed up before testing and check the temperature setting given in the manufacturer's data and test accordingly.

(5) Always follow the procedure given by the manufacturers for the test sequence and make sure that you understand the method of adjustment.

(6) Make all tests with the cover in place, particularly where a metal cover is used. Do not remove or refit the cover until you have first disconnected the "Battery" cable.

(7) Take particular care to avoid touching the cut-out or accidentally closing its contacts while the engine is stationary, as this will cause a heavy discharge through the regulator and cut-out circuits.

(8) Lock all adjustments after setting, where locking nuts, etc., are provided.

(9) Check the uniformity of operation after setting to ensure that the regulator will perform its work reliably.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 10

AREA TESTING

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

AREA TESTING

The Motor Industry has never been stagnant, it has developed rapidly since its earliest days. Advances in engine and electrical design and the availability of better materials, lubricants and fuel have continuously increased engine power, speed, acceleration and economy and have made motoring continuously more dependable and enjoyable.

The most noteworthy advance has been the rapid improvement in engine performance. There has been no material change in basic engine components - cylinder blocks, pistons, valves and crankshafts are much as they were in the earliest days of the automobile engine. Yet, the modern engine gives vastly more power than earlier engines of the same weight. Today's normal engines are the equivalent of racing car engines of a few years ago. In only seven years the power output of standard automobile engines has increased by nearly fifty per cent.

These improvements have not been achieved by any change in the basic components of the engine, they are due to better materials, lubricants and fuels and - in particular - to engine design. Today's engines run at higher speeds, have much higher compression ratios and improved volumetric efficiency. They are designed and built to closer limits and have many complex and critical circuits and components.

The present day engine is a masterpiece of power and economy, but only while it is working within the extremely close limits, clearances and specifications established by the designer and built into the engine at the factory. These close limits and settings must be maintained and unless this is done the engine cannot give its full performance and economy.

When a vehicle leaves the factory with everything working to the established factory limits, clearances and specifications, it will give new car performance. As the vehicle is used the original standards alter. Moving parts wear, terminals become corroded, springs get weak and passages become clogged. Because of this the original performance and economy of the vehicle gradually declines. The change is very slow and is usually not noticed by the owner until it becomes obvious in noticeable loss of performance or specific trouble. The vehicle is then taken to a service shop to have the trouble diagnosed and corrected and normal performance restored.

THE SERVICE SHOP'S RESPONSIBILITY

Since the beginning of the Motor Industry it has been the responsibility of the service shop to:-

1. Find out what is wrong.

2. Sell only the service needed.

3. Do good repair work.

4. Prove that the work has been properly done.

If these principles are adhered to, good standards of service and customer satisfaction will be ensured. If they are violated by "guesstimating", doing work in the hope that trouble will be put right and failing to prove that the work has been properly done, the result will be misunderstandings, ill will, customer dissatisfaction and "come backs".

In earlier years when engines were relatively simple an experienced mechanic with a few tools could do an acceptable engine testing and tuning job. His knowledge, training and accumulated skill and experience was sufficient to enable him to diagnose the cause of trouble by practical tests and experiments and carry out the tuning adjustments needed which, in earlier days, were not unduly critical. Today, however, this is no longer practical. Engines have now become complicated and crowded with critical and inaccessible equipment. Road testing has become difficult and even hazardous. Troubles are more difficult to find and adjustments have to be made to extremely critical limits. No longer is it possible to carry out good engine testing and tuning with the speed and accuracy now essential by human endeavour alone. The skill and experience of mechanics must now be aided with proper testing tools and practical test procedures.

Testing tools and procedures are not new, they have been available for many years in the form of specialised motor analysers. They have, however, only been partially successful. Some service shops have used analysers successfully but, in many cases, the opposition of staff, the problem of finding a suitable operator, the expense and inconvenience of training, the dependence on an individual operator, the cost of the equipment, the time needed for testing and the strain on management have been too great. This has ultimately led to the equipment becoming used only when everything else has failed and in some cases, falling into complete disuse.

A NEW APPROACH.

Because of the difficulties experienced with earlier types of test equipment, leading car and equipment manufacturers have co-operated in the development of a new and more simple method of testing. This is known as Area Testing and is more simple and less expensive than earlier methods. It enables the modern complicated and critical engine to be tested and tuned quickly, easily and accurately with the standards of labour available today and enables the types of service needed on modern cars to be profitably performed.

The basic difference between Area Testing and earlier methods of engine testing is the principle of testing employed. With earlier test equipment

FIG. 1 CONVENTIONAL TESTING

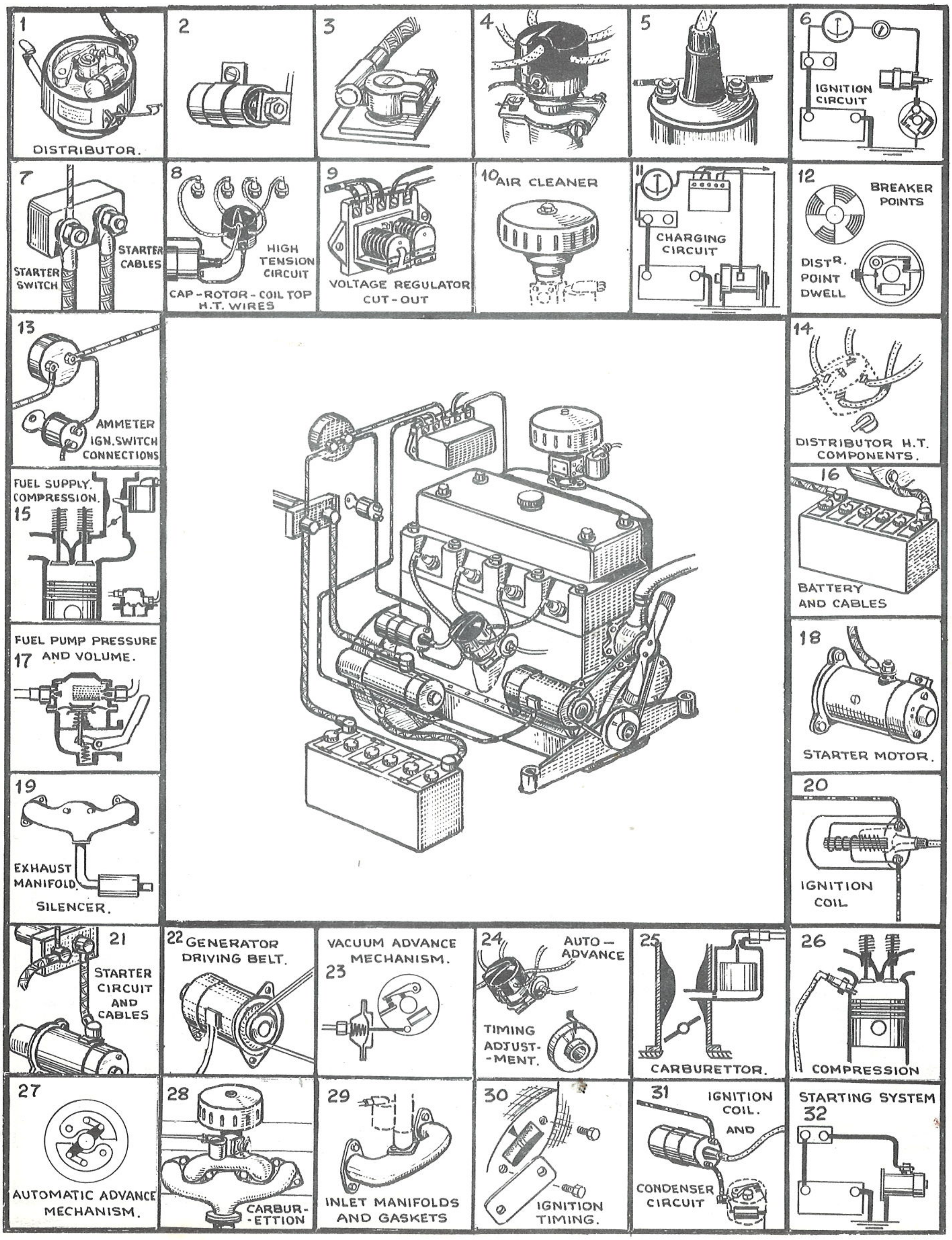
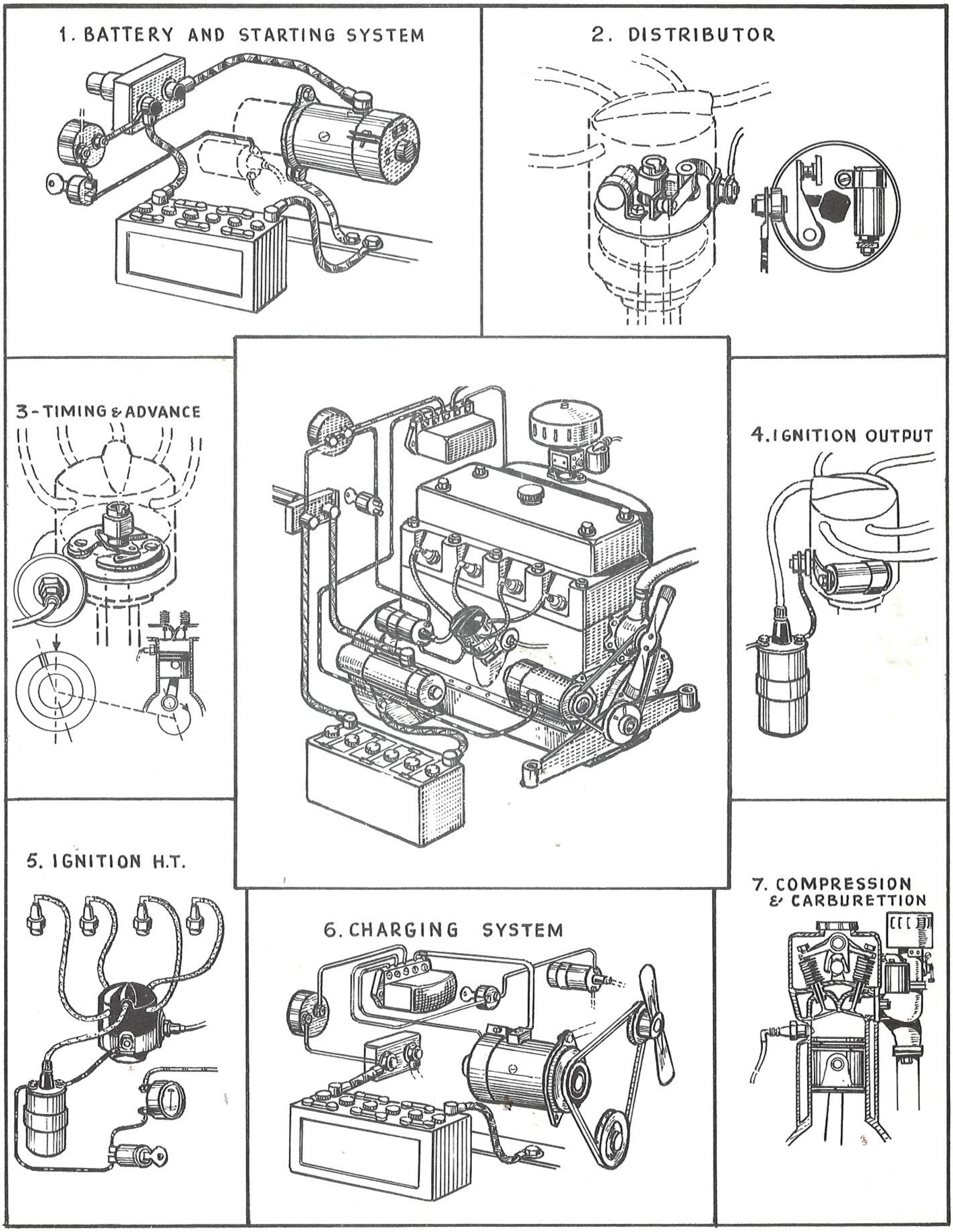

1
DISTRIBUTOR.
2
3
4
5
6
IGNITION CIRCUIT
7
STARTER SWITCH
STARTER CABLES
8
HIGH TENSION CIRCUIT
CAP-ROTOR-COIL TOP H.T. WIRES
9
VOLTAGE REGULATOR CUT-OUT
10 AIR CLEANER
11
CHARGING CIRCUIT
12
BREAKER POINTS
DISTR. POINT DWELL
13
AMMETER IGN. SWITCH CONNECTIONS
14
DISTRIBUTOR H.T. COMPONENTS.
FUEL SUPPLY. COMPRESSION.
15
16
BATTERY AND CABLES
FUEL PUMP PRESSURE AND VOLUME.
17
18
STARTER MOTOR.
19
EXHAUST MANIFOLD.
SILENCER.
20
IGNITION COIL
21
STARTER CIRCUIT AND CABLES
22 GENERATOR DRIVING BELT.
VACUUM ADVANCE MECHANISM.
23
24
AUTO-ADVANCE
TIMING ADJUST-MENT.
25
CARBURETTOR.
26
COMPRESSION
27
AUTOMATIC ADVANCE MECHANISM.
28
CARBUR-ETTION
29
INLET MANIFOLDS AND GASKETS
30
IGNITION TIMING.
31
IGNITION COIL. AND
CONDENSER CIRCUIT
STARTING SYSTEM
32

FIG. 2 AREA TESTING


1. BATTERY AND STARTING SYSTEM
2. DISTRIBUTOR
3 - TIMING & ADVANCE
4. IGNITION OUTPUT
5. IGNITION H.T.
6. CHARGING SYSTEM
7. COMPRESSION & CARBURETTION

it was necessary to test all circuits and components individually. As engines became more complicated and crowded this method necessarily involved increasing skill and longer time. With the new method of Area Testing it is no longer necessary to test circuits and components individually, they are tested in groups. New electronic instruments have been designed which, with a single connection and by making only a single test, show the end-result of the combined operation of selected groups of circuits and components. The engine is divided into seven groups or areas which are tested in turn. Only seven tests are needed to check the entire engine and these are always the same.

The difference between the earlier methods of testing and the modern method of Area Testing is shown in Figures 1 and 2. Figure 1 illustrates the many different components which have to be individually inspected, tested and experimentally adjusted with conventional methods of testing.

Figure 2 shows the seven groups of circuits and components, each of which is checked with a single test so simple that any mechanic can, without difficulty, do the job. The time required for testing has been reduced from several hours to an average of ten to twenty minutes.

HOW TO APPLY AREA TESTING.

There are three basic applications of Area Testing in the modern automobile service shop:-

1. For general workshop servicing
2. As a preventive maintenance service
3. For the promotion of new and used car sales

The same basic method of testing and tuning is used for all these applications. Only one item of equipment is used, only seven tests are employed and these are always the same.

Area Testing in the Workshop.

Area Testing can be employed in the workshop for all basic requirements in engine performance servicing, including:-

1. Correcting specific troubles such as missing, pinking, hard starting and stalling.
2. Correcting performance complaints such as poor acceleration, lack of power or loss of top speed.
3. Checking over and tuning a car before a long journey or holiday trip.
4. Checking engines after repair to prove service quality.

5. Tuning repaired engines to ensure good performance and economy.

6. Appraising the engine condition of "trade-ins" to enable engine conditioning requirements to be more easily assessed.

To secure the full benefits of Area Testing it should be made a routine pre-repair and post-repair operation. It is necessary to resist the temptation of making an Area Test only as a last resort. If Area Testing is used regularly both before and after repair it will ensure lower testing times, more accurate diagnosis, more intelligent and complete repair orders, better final performance and assured customer satisfaction.

Performance Maintenance Tune-up.

Crypton Equipment Ltd. have designed a special application of Area Testing called "SUPERTUNE" Performance Maintenance Service. This consists of a preliminary inspection of the engine, followed by an Area Test and includes a number of standard tune-up adjustments such as spark plugs, ignition timing, carburettor, breaker points and engine idle R.P.M.

The purpose of "SUPERTUNE" is to enable car owners at reasonable cost to have their engines scientifically tested and tuned at regular mileage intervals to confirm the continued good condition of the engine and ensure that it is maintained at peak performance and economy. The attractive price at which the service can be offered appeals to many car owners and has enabled many specialising service shops to build up a large and profitable business.

New and Used Car Sales.

Area Testing is a unique development in service because it makes a major contribution to the sale of new and used cars as well as promoting easier, quicker and better engine service work.

Used Car Sales can be improved by giving the owner an Area Test Report which confirms the good condition of the engine. The engine can also be tuned to the accurate limits now essential to secure good performance and economy, thus helping to ensure first class demonstrations with engines easy to start, and which idle smoothly, and with good acceleration and fast safe top speed.

New Car Sales can be improved through quicker and more accurate pre-delivery checks. Prospective new car customers are impressed when they are introduced to the modern approach to service which is behind the new cars for sale. When they have bought their car they like to know that it will be electronically tested for perfection of engine condition and performance. They are impressed when told that the same modern approach to service will be used for the "running in" servicing of their vehicles. They are also appreciative if one or more bonus tune-up services are offered at early mileage intervals during the life of their car.

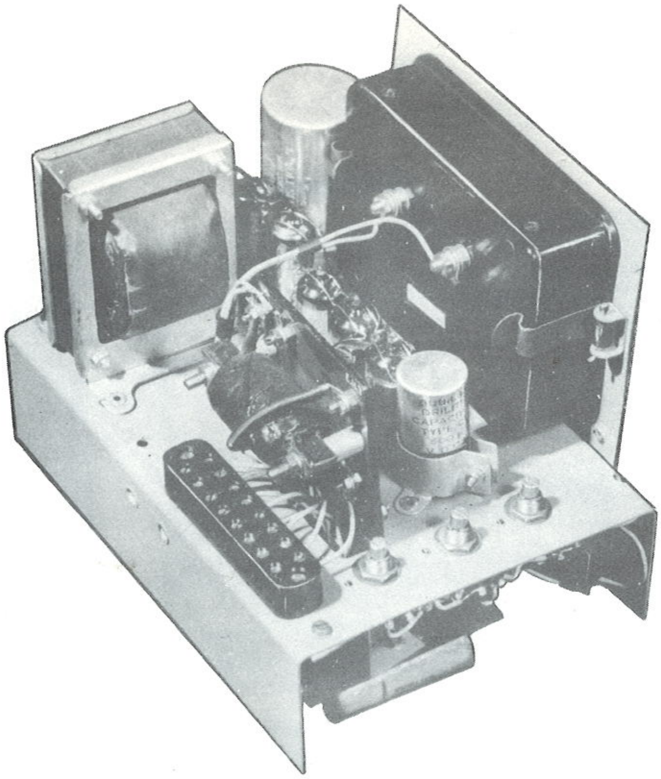


FIG. 5 AUTO-ADVANCE CHASSIS

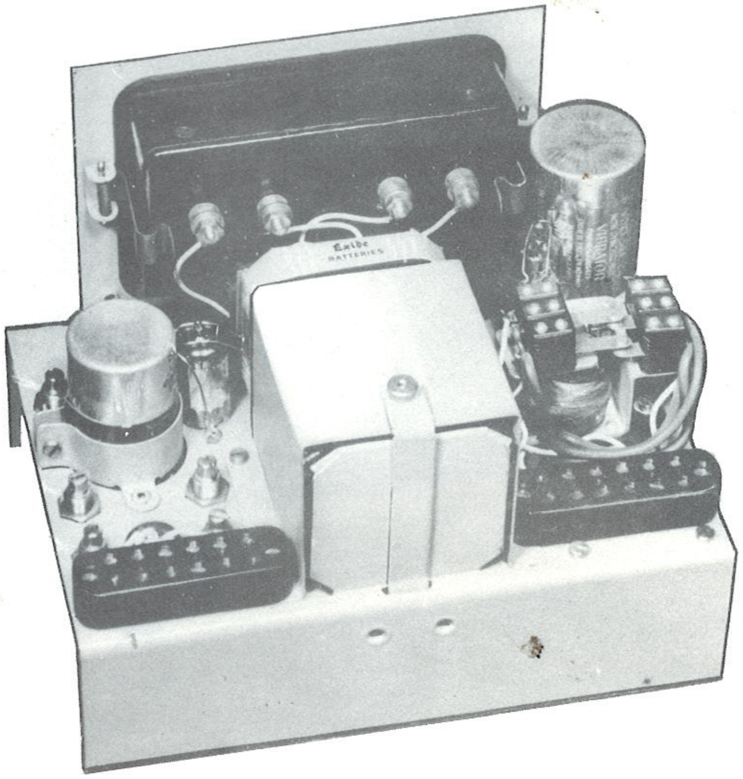

Exide
BATTERIES

FIG 6. TACH-DWELL-VOLTMETER CHASSIS

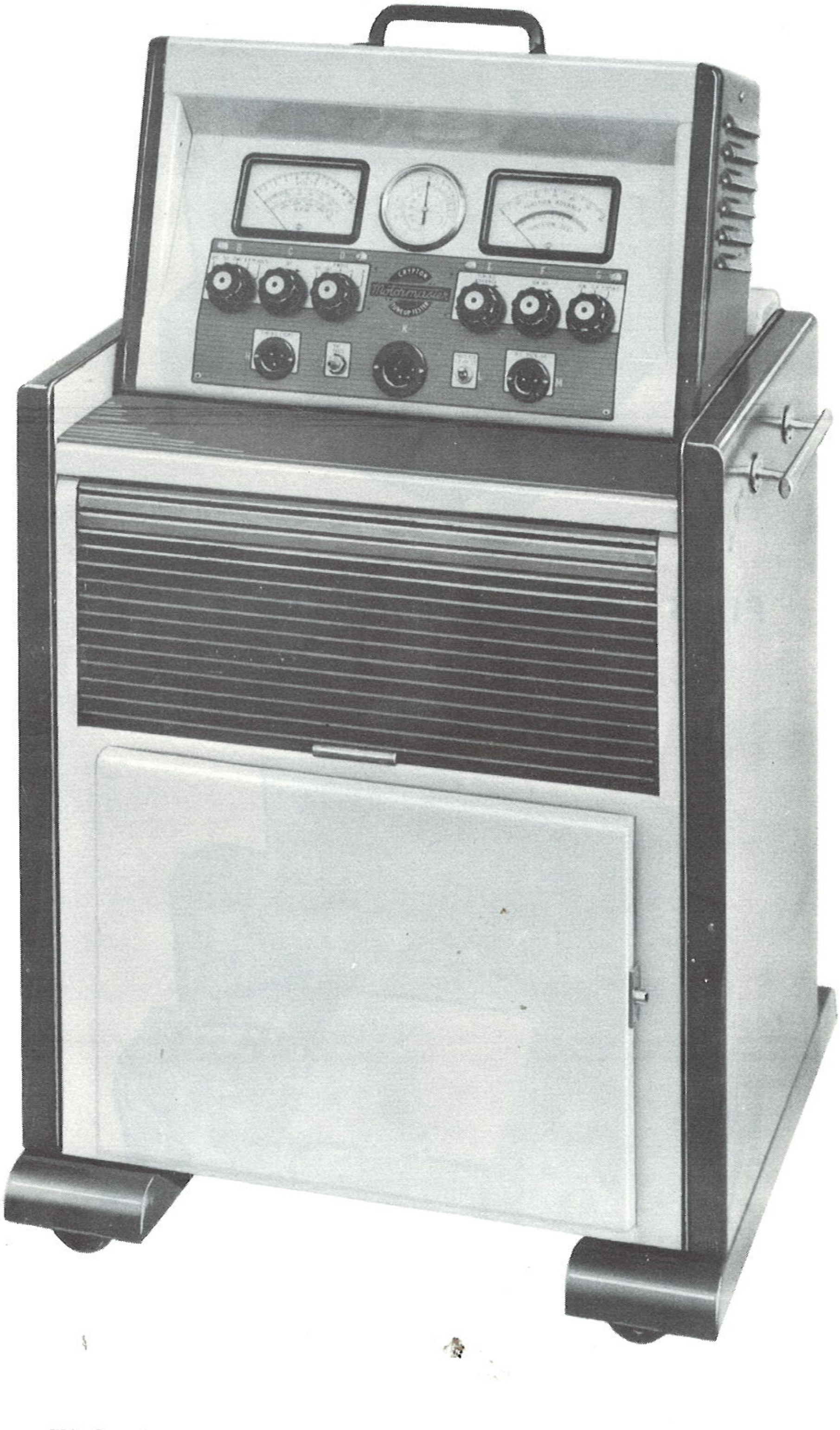
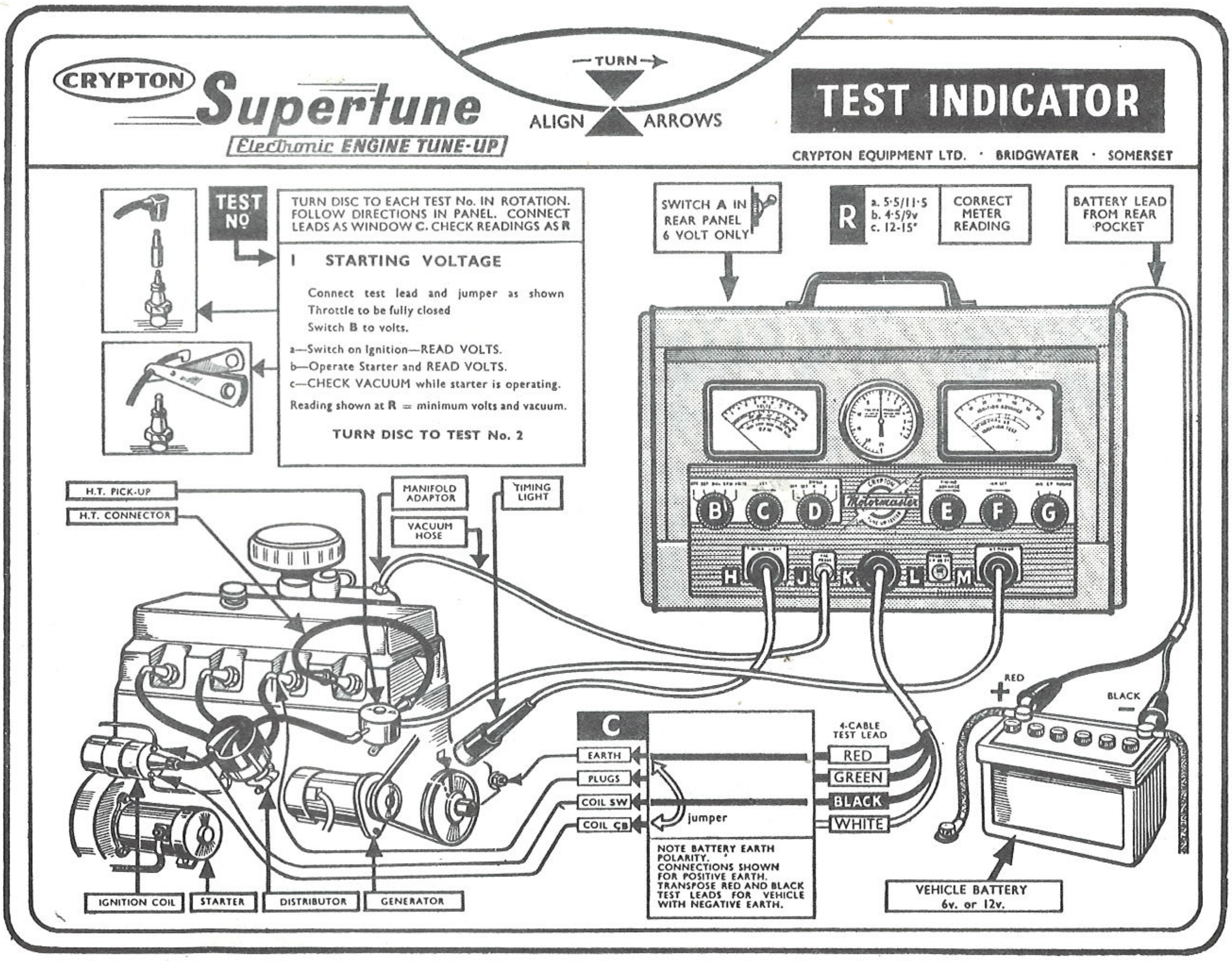

CRYPTON
Motormaster
TUNE-UP TESTER

FIG.7

CRYPTON ROTARY TEST GUIDE

A Testing Slide Rule for the Operation of Fast Accurate Area Testing.


CRYPTON
Supertune
Electronic ENGINE TUNE-UP
TURN
ALIGN
ARROWS
TEST INDICATOR
CRYPTON EQUIPMENT LTD. · BRIDGWATER · SOMERSET
TEST Nº
SWITCH A IN REAR PANEL 6 VOLT ONLY
R
a. 5·5/11·5
b. 4·5/9v
c. 12-15"
CORRECT METER READING
BATTERY LEAD FROM REAR POCKET
H.T. PICK-UP
H.T. CONNECTOR
MANIFOLD ADAPTOR
VACUUM HOSE
TIMING LIGHT
B
C
D
E
F
G
H
J
K
L
M
C
EARTH
PLUGS
COIL SW
COIL CB
jumper
4-CABLE TEST LEAD
RED
GREEN
BLACK
WHITE
RED
+
BLACK
−
VEHICLE BATTERY 6v. or 12v.
IGNITION COIL
STARTER
DISTRIBUTOR
GENERATOR

TURN DISC TO EACH TEST No. IN ROTATION. FOLLOW DIRECTIONS IN PANEL. CONNECT LEADS AS WINDOW C. CHECK READINGS AS R

I STARTING VOLTAGE

Connect test lead and jumper as shown
Throttle to be fully closed
Switch B to volts.

a—Switch on Ignition—READ VOLTS.
b—Operate Starter and READ VOLTS.
c—CHECK VACUUM while starter is operating.

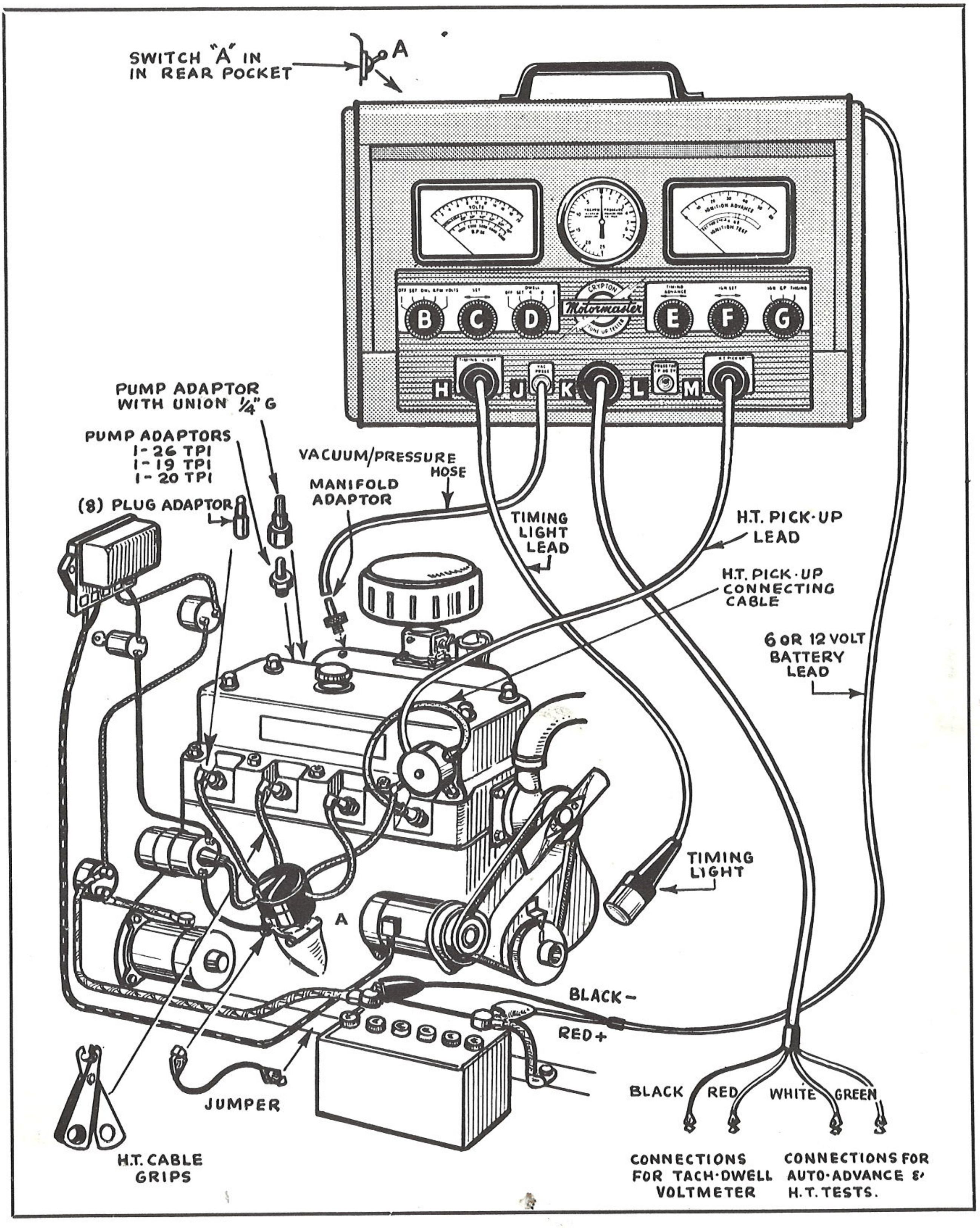
Reading shown at R = minimum volts and vacuum.

TURN DISC TO TEST No. 2

NOTE BATTERY EARTH POLARITY. CONNECTIONS SHOWN FOR POSITIVE EARTH. TRANSPOSE RED AND BLACK TEST LEADS FOR VEHICLE WITH NEGATIVE EARTH.

FIG. 4

This unique presentation of Area Testing information and test instructions show at a glance the leads to use—where to connect them—how to test and the correct test reading. All this information is automatically unfolded as the operator turns the disc.


SWITCH "A" IN
IN REAR POCKET
A
Motormaster
CRYPTON
TUNE UP TESTER
B
C
D
E
F
G
H
J
K
L
M
PUMP ADAPTOR
WITH UNION ¼" G
PUMP ADAPTORS
1-26 TPI
1-19 TPI
1-20 TPI
(8) PLUG ADAPTOR
VACUUM/PRESSURE
HOSE
MANIFOLD
ADAPTOR
TIMING
LIGHT
LEAD
H.T. PICK-UP
LEAD
H.T. PICK-UP
CONNECTING
CABLE
6 OR 12 VOLT
BATTERY
LEAD
TIMING
LIGHT
A
BLACK -
RED +
JUMPER
H.T. CABLE
GRIPS
BLACK
RED
WHITE
GREEN
CONNECTIONS
FOR TACH-DWELL
VOLTMETER
CONNECTIONS FOR
AUTO-ADVANCE &
H.T. TESTS.

Illustrating the Motormaster with all Switch Adjustments made, Auxilliary Units connected and Test Leads connected for Supertune Area Testing.

CRYPTON "*Motormaster*" TEST RECORD

OWNER .... DATE ....
ADDRESS ....
.... PHONE ....
MAKE .... MODEL ....
REG. No. .... MILEAGE .... SER. ORDER ....

VISUAL CHECKS **CONDITION**
Fan Belt ....
Air Cleaner ....
Battery Cables ....
Cooling System ....
Fuel System ....

INITIAL TESTS | RECTIFICATION AND RE-TEST

1 SPARK PLUGS—condition .... ☐ .... ☐
2 COMPRESSION—uniformity .... ☐ .... ☐

	1	2	3	4	5	6	7	8
Dry								
Oil								

☐ .... ☐
☐ .... ☐

3 H.T. CABLES—condition and connections .... ☐ .... ☐
4 BATTERY—state of charge and condition .... ☐ .... ☐

Connect "Motormaster" Tester

5 BATTERY—volts at coil .... ☐ .... ☐
6 BATTERY—starting volts .... ☐ .... ☐
7 VACUUM—on starter load .... ☐ .... ☐
8 BREAKER POINTS—Volt drop .... ☐ .... ☐
9 DISTRIBUTOR—dwell angle .... ☐ .... ☐
10 DISTRIBUTOR—dwell variation .... ☐ .... ☐
11 IGNITION TIMING—at 500 r.p.m. .... ☐ .... ☐
12 AUTOMATIC ADVANCE—at ________ r.p.m. .... ☐ .... ☐
13 IGNITION OUTPUT .... ☐ .... ☐
14 CYLINDER BALANCE—vacuum drop .... ☐ .... ☐
15 COIL POLARITY .... ☐ .... ☐
16 IGNITION SECONDARY RESISTANCE —........ ☐ .... ☐

1	2	3	4	5	6	7	8

☐ .... ☐

17 CHARGING VOLTAGE— .... ☐ .... ☐
18 INDUCTION VACUUM— .... ☐ .... ☐
20 CYLINDER POWER OUTPUT .... ☐ .... ☐

1	2	3	4	5	6	7	8

☐ .... ☐

21 ENGINE IDLE R.P.M.— .... ☐ .... ☐
22 CARBURETTOR—air fuel ratio— .... ☐ .... ☐

FIG. 3

CA 453

A SUMMARY OF AREA TESTING

Area Testing is a noteworthy development in the promotion of lower cost, better quality engine performance servicing.

The summarised applications for which it can be applied are as follows:-

(1) FOR CORRECTING ALL ENGINE COMPLAINTS such as missing, pinking, hard starting, stalling, rough running or engine overheating.

(2) RESTORING LOST PERFORMANCE for application when the customer complains that the engine has become sluggish, has lost its petrol consumption or that mileage is low.

(3) TO CONFIRM THE NEED OF NEW PARTS such as sparking plugs, new breaker points, etc. Customers often ask for these new parts to be fitted and appreciate an offer to make a quick check of the engine to ensure that they are necessary. Such a check will often disclose the fact that other parts or additional parts are needed.

(4) FOR LONG JOURNEY AND HOLIDAY SERVICING where the owner wants his engine checked over and tuned before taking the vehicle on a long journey or making a holiday trip.

(5) FOR CHECKING OVER SERVICED ENGINES to ensure that repairs have been properly made.

(6) FOR TUNING ENGINES AFTER REPAIR to ensure that normal performance has been restored and that the customer will be satisfied.

(7) AS A PERFORMANCE MAINTENANCE SERVICE - this comprises a complete engine tune-up carried out at 3,000 to 5,000 mile intervals to confirm the continued good condition of the engine and ensure maintained peak power and economy.

(8) FOR APPRAISING THE ENGINE CONDITION OF "TRADE-INS" - this ensures that reliable information is obtained of the condition of the engine and enables reconditioning service needs to be more easily assessed.

(9) FOR IMPROVING USED CAR SALES by giving proof to prospective customers of the good engine condition of the car and also securing improved demonstration performance.

(10) FOR IMPROVING NEW CAR SALES through quicker and more accurate pre-delivery checks of new vehicles, and impressive confidence-creating after-sale servicing facilities.

HOW TO PERFORM AN AREA TEST.

An Area Test comprises seven standard sequence tests, the order of which is shown in Figure 3. Each test covers a specific area of the engine and enables the condition and operation of selected groups of circuits and components to be quickly and accurately established.

The order of testing has been carefully developed to ensure complete accuracy with maximum speed and greatest simplicity. The number of connections and disconnections is reduced to a minimum and the mechanic goes smoothly through the entire engine, guided by the instrument readings which disclose the condition of each section of the engine in turn.

An Area Test will not necessarily and immediately locate the exact cause of trouble. It shows the area of the engine responsible for trouble but further tests may be necessary to pinpoint the exact fault. This can be done by using the Area Test instruments supplemented where required with additional time-saving instruments such as a Compression Tester, Battery Capacity Tester, Exhaust Gas Analyser and Coil and Condenser Tester.

THE CRYPTON ROTARY TEST GUIDE.

The Crypton Rotary Test Guide shown in Figure 4 is the equivalent of a "testing slide rule" for carrying out the standard Seven Point Area Test. It consists of an envelope with a central rotating disc with information appearing through windows in the envelope. The envelope contains a picture of the tester, the connecting leads and the engine. The Guide is so designed that, as the operator rotates the disc, he can see at a glance:-

(1) The leads to use.

(2) Where to connect them

(3) How to make the test

(4) The correct readings for the test.

The Guide is not only of time-saving value to the operator, but intriguing to the car owner. It shows him the interesting and complete tests made to confirm the condition of his engine and accurately locate the cause of actual or impending trouble.

EQUIPMENT NEEDED FOR AREA TESTING

Area Testing has been made possible by the development of new electronic instruments which enable "end result" tests to be made of selected groups of engine circuits and components instead of testing them individually. Two basic instruments are employed - an Automatic Advance and Ignition Test Unit as shown in Figure 5, and a Combined Electric Tachometer, Dwell Tester and Voltmeter as shown in Figure 6.

For convenience of application the two instruments are combined to form a complete test set. Figure 7 shows how this is done to form a portable tester, the Crypton "MOTORMASTER" where the two basic instruments are combined with a Vacuum - Pressure Gauge and a series of master switches and controls to form a compact, fully equipped portable Area Tester. Figure 8 is a de-luxe presentation of the two basic instruments, presented in the form of a complete Engine Performance Bay. Larger size test meters are employed and additional test meters fitted and other refinements are provided such as retracting leads, remote control testing features, framed test and data charts and other refinements.

The basic principle of testing is the same for all types of Area Test equipment. In all cases only seven standard electrical tests are made.

Before actually making the electrical test a number of preliminary inspections and operations should be made. These uncover many possible causes of trouble and make the instrument tests even more accurate.

PRELIMINARY OPERATIONS.

Before commencing to make any instrument tests it is recommended that the following preliminary inspections and operations are carried out.

1. SPARK PLUGS. The spark plugs should be removed, carefully inspected, cleaned, regapped and tested. This ensures that the spark plugs are of the correct type and in good condition.

   If the inspection shows any signs of wear, cracks, chips, electrode oxidisation and indications of leakage, new spark plugs should be recommended. It is important to see that the plugs are of the correct type. When refitting plugs use new gaskets.

2. CYLINDER COMPRESSION. Wherever possible a test should be made of cylinder compression. This is important because no engine can give its normal power unless compression conditions are satisfactory.

   When making a compression test, the engine must be at normal operating temperature - this is important.

   The test is made with the spark plugs removed and a Compression Tester inserted into No.1 spark plug hole. The engine is cranked for a minimum of five compression strokes, the reading being carefully noted for the first and final strokes. The test is repeated for the same number of revolutions on all cylinders.

   Compression conditions are satisfactory if the compression builds up quickly and evenly to normal values for each cylinder with less than 10 lbs. variation between the highest and lowest readings. If the readings are low or uneven, inject a small quantity of thin oil through the plug holes of the doubtful cylinders and repeat the test.

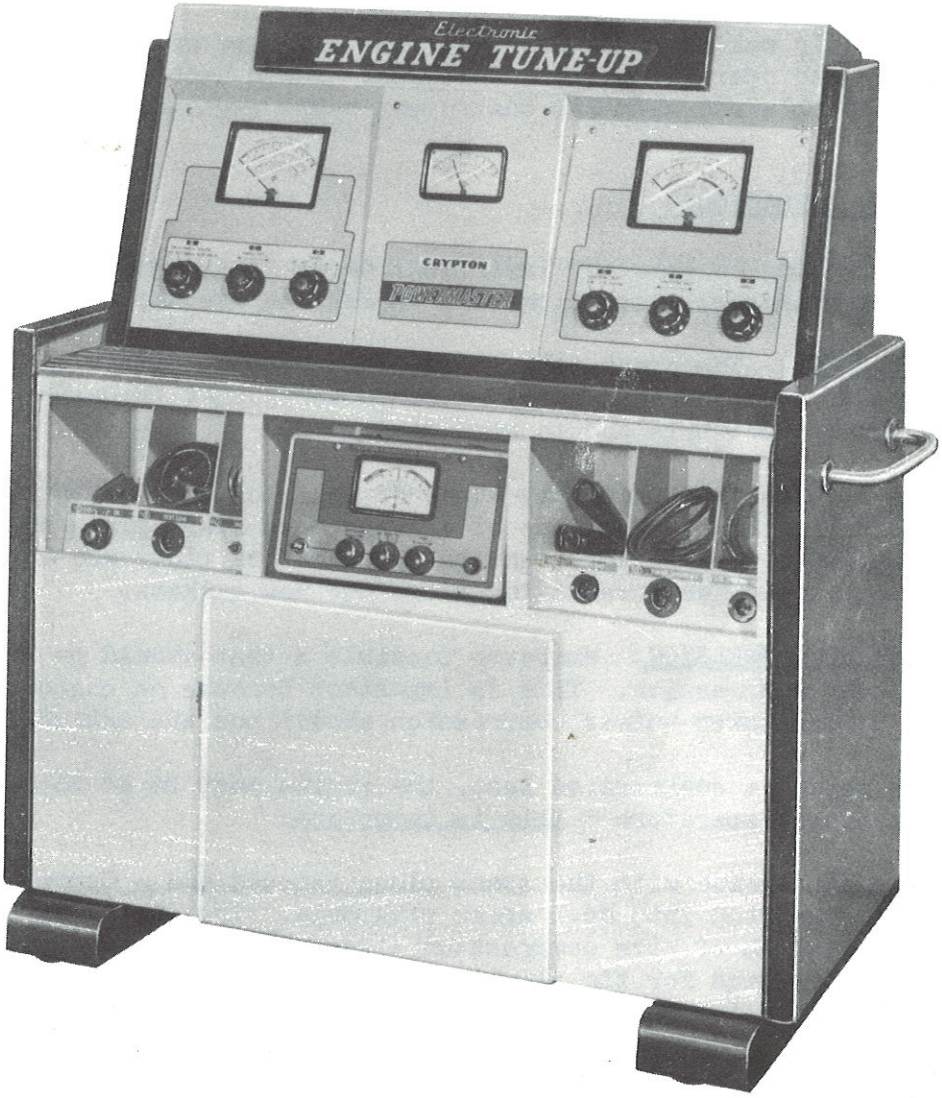

Electronic
ENGINE TUNE-UP
CRYPTON
POWERMASTER

FIG. 8

Piston ring trouble is indicated where the compression is low on the first stroke, tends to build up on following strokes, but does not reach normal and then improves with the addition of oil.

Valve trouble is indicated where the compression is low on the first stroke, does not build up on following strokes and does not improve much with the addition of oil.

A leaky head gasket is indicated where compression on the first stroke is low on two adjacent cylinders.

3. IGNITION H.T. COMPONENTS. An overall inspection should be made of the ignition H.T. components. The distributor cap and rotor should be checked for cracks and excessive burning. Cable connections should be carefully checked and the cables inspected for signs of cracking or perishing. The coil cap and the wire from the coil to the distributor should be also inspected.

4. DISTRIBUTOR BREAKER POINTS. A visual check should be made of the breaker points and the condition of the contact surfaces. If the contacts are pitted, burned or misaligned, a new set should be fitted. After inspection the auto advance mechanism should be sparingly lubricated.

5. IGNITION PRIMARY CIRCUIT. All wiring and connections should be carefully inspected and tightened - look particularly for frayed cable ends or badly soldered tags.

6. BATTERY STATE-OF-CHARGE. The battery should be tested for the state-of-charge of all cells. This is most quickly done by using the Crypton "Hydrolek" Battery Tester. All cells should read in the "SERVICEABLE" zone of the Tester. If the meter reads in the "RECHARGE" zone and the readings do not vary by more than six points, the need of re-charging is indicated. If there is a variation of six points or more between cell readings, the battery should be recharged and re-tested.

7. FAN BELT. The condition of the fan belt is important and should be carefully checked. Tension should also be tested, the belt should flex about half an inch under finger pressure.

8. FUEL SYSTEM. Carefully check the fuel system throughout. See that the fuel lines are free from leaks and are not broken or loose. Check the mounting of the fuel pump and see that there are no loose screws. Look for dirt or sediment in the filter bowl. Check the electrical connections of electric type pumps.

Have a careful look at the carburettor and check for loose screws or worn or missing linkage.

HOW TO MAKE THE INSTRUMENT TESTS

The procedure for making the seven instrument tests which comprise the complete Area Testprocedure are explained in detail in the following pages. The instructions apply either to the Crypton "Motormaster" or Engine Performance Servicing Bay. The leads used are the same in both cases and the connecting points on the engine are also similar. To make instructions clear each test has its own diagram, clearly showing the leads to use and where connections are made.

AREA TEST NO.1

BATTERY CRANKING VOLTAGE

The first Area Test checks the condition and efficiency of the battery and starting system. It covers the wiring from the battery to the ignition coil, the condition of the battery and cables, including earth connections, and the entire starting system, including the starter motor, starter switch and cables and connections.

Two measurements are made, firstly the voltage at the ignition coil and secondly the voltage of the battery while the starter is cranking the engine. The first test of the voltage at the ignition coil proves that the circuit from the battery to the coil is free from high resistance. This circuit is shown in Figure 9, and comprises the wiring from the battery negative post to the ammeter, ignition switch and coil "SW" terminal.

A test of the battery cranking voltage proves that the battery has adequate capacity for good starting and the performance of the starter confirms the condition of the starter motor, starter switch, cables and connections.

At the same time that the battery cranking voltage is tested a check can be made of the engine induction vacuum. The value and regularity of the induction value is a practical check of the uniformity of engine breathing. A low vacuum reading indicates the possibility of faulty inlet gaskets or valve seating.

How to Carry Out the Test

The test is made by connecting one lead of the test voltmeter to the ignition coil "SW" terminal and the other lead to the engine block. A jumper lead is connected between the distributor "CB" terminals and the cylinder block. These connections are shown in Figure 9 and apply to a vehicle with a positive earth return. If the vehicle has a negative earth the connections should be reversed.

With the gear lever in neutral and ignition "ON" the voltmeter shows the voltage at the coil. If this is within half volt of the battery voltage i.e., 11½ volts for a 12 volt system or 5½ volts for a 6 volt system, it shows that the circuit from the battery to the coil is good.

The starter is now operated to crank the engine and the voltmeter reading and starter response carefully noted. If the voltmeter reads not less than 9 volts for a 12 volt system and 4½ volts for a 6 volt system it shows the battery has adequate capacity for good starting. The starter cranking speed should be normal and even.

The vacuum reading during the test should be uniform and regular - usually 17 inches to 21 inches in a sound engine.

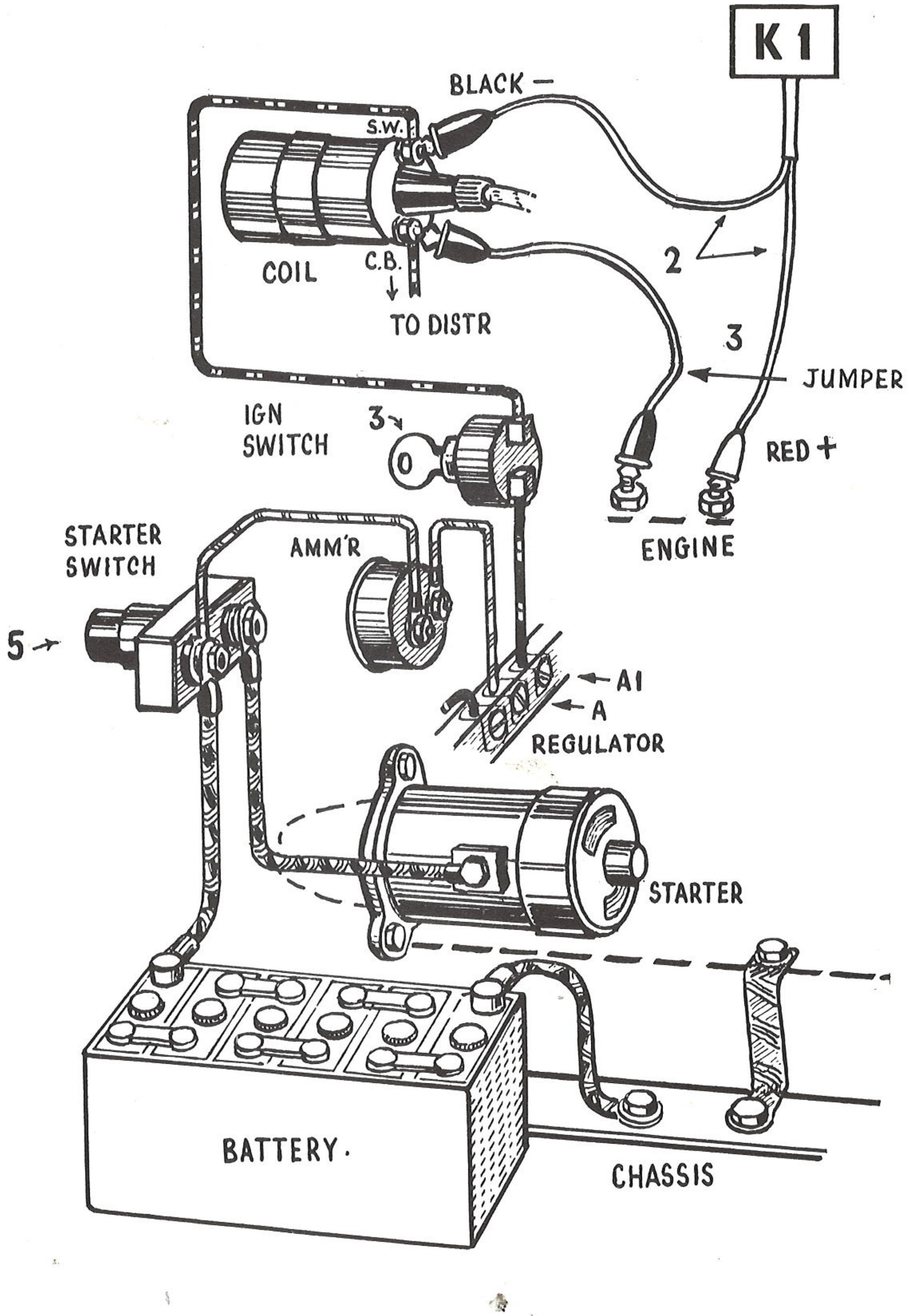

K 1
BLACK −
S.W.
COIL
C.B.
TO DISTR
2
3
JUMPER
RED +
IGN SWITCH
3
0
ENGINE
STARTER SWITCH
5
AMM'R
A1
A
REGULATOR
STARTER
BATTERY.
CHASSIS

FIG. 9. *CONNECTIONS FOR TESTING BATTERY CRANKING VOLTAGE*

AREA TEST NO.2.

DISTRIBUTOR RESISTANCE AND POINT VARIATION

The second test in the Area Test Procedure covers the distributor and verifies firstly the setting of the distributor breaker points and secondly the mechanical condition of the entire distributor.

The first test of breaker point condition is made by measuring the voltage drop across the contact points when they are closed. This shows if the points are electrically clean for good operation.

The second test of point setting and distributor mechanical condition is made by measuring the dwell angle (or cam angle) of the distributor. This is the time measured in degrees of distributor cam rotation whilst the points are closed. If the period of point closure measured in degrees is too high it shows the breaker points are too close, if too low it shows the points are too wide.

The mechanical condition of the distributor is checked by measuring the dwell angle at an engine speed of about 1500 R.P.M. The reading should be within three degrees of the dwell angle reading at idling speed. If there is a variation of more than 3 degrees it shows excessive wear of distributor shaft and bushes.

How to Make the Test.

The test is made by connecting the two test leads of the Tach-Dwell-Voltmeter unit to the ignition coil "CB" terminal and cylinder block respectively, as shown in Figure 10.

Simple instrument adjustments are made, the ignition switched "ON" and the breaker points closed. The voltmeter reading is then noted and should not exceed 0.2 volts. If the reading is higher than 0.2 volts it shows excessive resistance of breaker contacts and the need of cleaning or preferably replacement.

The engine is now run at a low steady idle to check for the condition of distributor spindle and cam lobes. The needle reading should be absolutely steady - if there is a rhythmic waver it indicates a bent spindle or worn cam lobes.

With the engine running at idle the dwell angle is checked by making a simple adjustment of the Tester. This must comply with the manufacturer's dwell angle - or cam angle - settings for the type of distributor tested. If the dwell angle is outside the manufacturer's limits distributor reconditioning is required.

The test is completed by increasing the engine speed to 1500 R.P.M. and again noting the dwell angle. This must be within 3 degrees of the dwell angle at engine idle R.P.M.

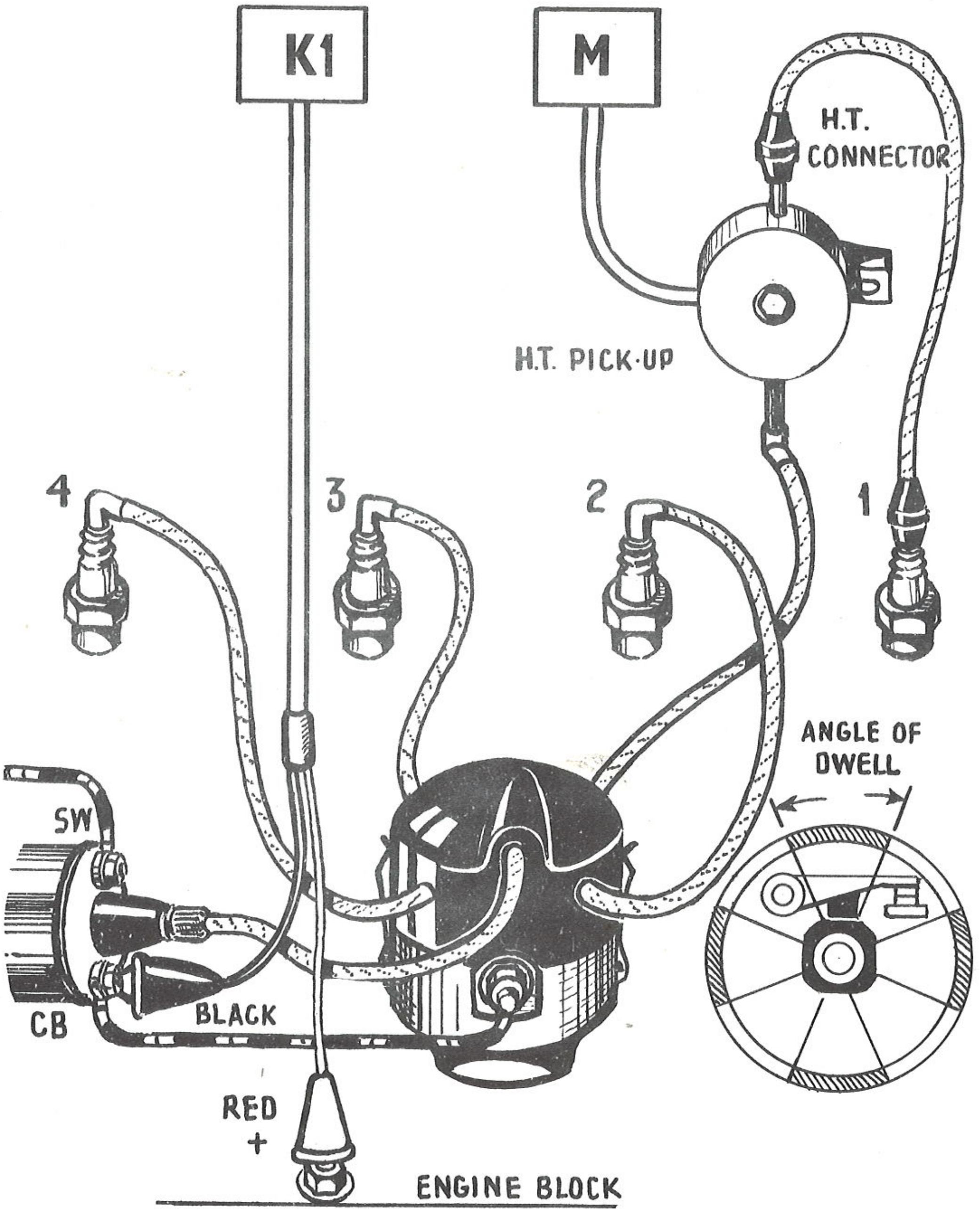

K1
M
H.T. CONNECTOR
H.T. PICK-UP
4
3
2
1
ANGLE OF DWELL
SW
CB
BLACK
RED
+
ENGINE BLOCK

FIG.10 *CONNECTIONS FOR TESTING DISTRIBUTORS*

AREA TEST NO.3.

IGNITION TIMING AND AUTOMATIC ADVANCE

This third test in the Area Test Procedure tests ignition timing and automatic advance without removing the distributor from the engine.

Accurate ignition timing and automatic advance testing is a vital need in servicing modern engines. Both ignition timing and automatic advance must be strictly within the manufacturer's standards to ensure full power. A variation of only two or three degrees in timing can result in a loss of up to 10 per cent. of engine power. Spark plug temperatures are also very critical to ignition timing, a variation of only two degrees will cause plugs to overheat by as much as 30 per cent.

A new principle of phased stroboscopic ignition timing measures both the initial timing and automatic advance. This comprises a special electronic circuit used in conjunction with a power timing light and integrated controls. Although complex in its design the testing circuit is extremely robust and reliable and the actual operation of the test is very simple.

How to Test Ignition Timing and Automatic Advance.

To make the test a special electronic timing light and high tension pick-up are connected to No.1 spark plug as shown in Figure 11.

With the battery leads connected to the vehicle battery and the engine running at idling speed ignition timing is tested by using the timing light to observe the position of the timing mark in relation to the timing pointer. This is shown in Figure 11. Where only T.D.C. marks are provided a control on the Tester is adjusted until the marks line up, when the Test Meter shows the degrees before T.D.C. to which the engine has been set. The test shows immediately the setting of the distributor and if (as is often the case) an adjustment is needed this can be made by moving the distributor until the required setting, as indicated by the meter reading, is obtained.

To test automatic advance the distributor vacuum unit is first disconnected and the engine speed increased to any required R.P.M. When this is done the timing marks will appear to move. A control on the test equipment is now adjusted until the marks line up again. The Auto-advance Meter will now show the degrees of centrifugal advance. The measurement is in crankshaft degrees i.e., twice distributor degrees.

The test made shows the centrifugal advance. To make a test of the vacuum advance the vacuum unit is reconnected and the test repeated. The meter will now show the total centrifugal and vacuum advance. By subtracting the reading of the first centrifugal advance figure the vacuum advance can be obtained.

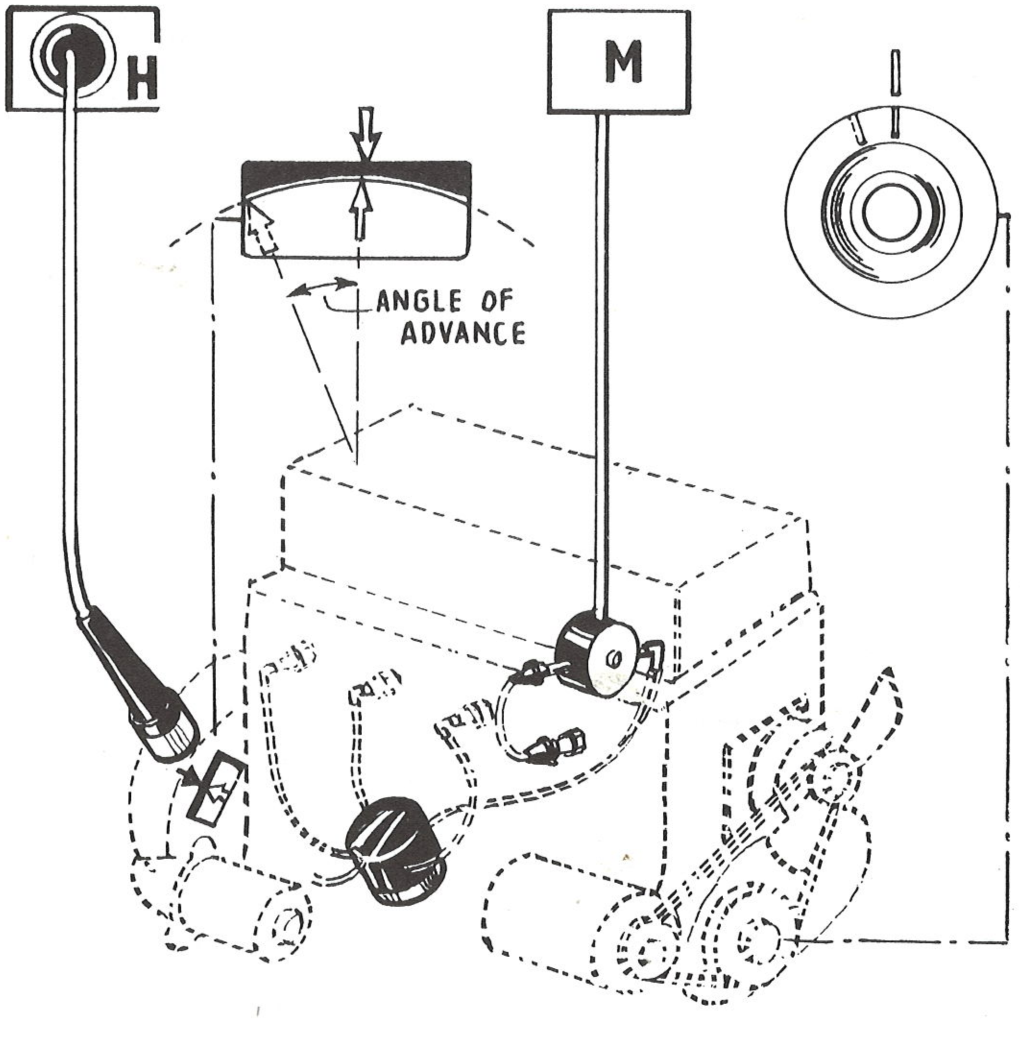

H
M
ANGLE OF ADVANCE

FIG. 11 *CONNECTIONS FOR TESTING AUTOMATIC ADVANCE*

AREA TEST NO.4.

IGNITION OUTPUT AND SECONDARY LEAKAGE

The fourth test of the Area Test Procedure makes a comprehensive check of the ignition system with the engine running. It provides a quick check of the entire ignition system with the exception of the distributor cap and spark plug wires. It serves as a quick check of the coil and condenser.

At the same time that ignition is being tested a check can be made of the power contribution from each cylinder to check power balance and disclose possible misfiring or weak cylinders. This is done by measuring the drop in the vacuum reading for each cylinder.

How to Make the Test

The test is made by connecting two ignition test leads to the ignition coil terminals as shown in Figure 12. The engine is run at a steady speed of approximately 1,000 R.P.M.

A control on the test instrument is adjusted to compensate for the number of engine cylinders and the plug leads are then removed and replaced one at a time, using special insulated pliers provided.

As each plug lead is removed the test meter needle should move into a "GOOD" zone. This shows that the output of the ignition system is normal and that there is no excessive secondary insulation leakage.

As each spark plug lead is removed the drop in vacuum reading should be noted. All cylinders should give an equal drop in vacuum. Cylinders which give a lower vacuum drop than others are deficient in power contribution.

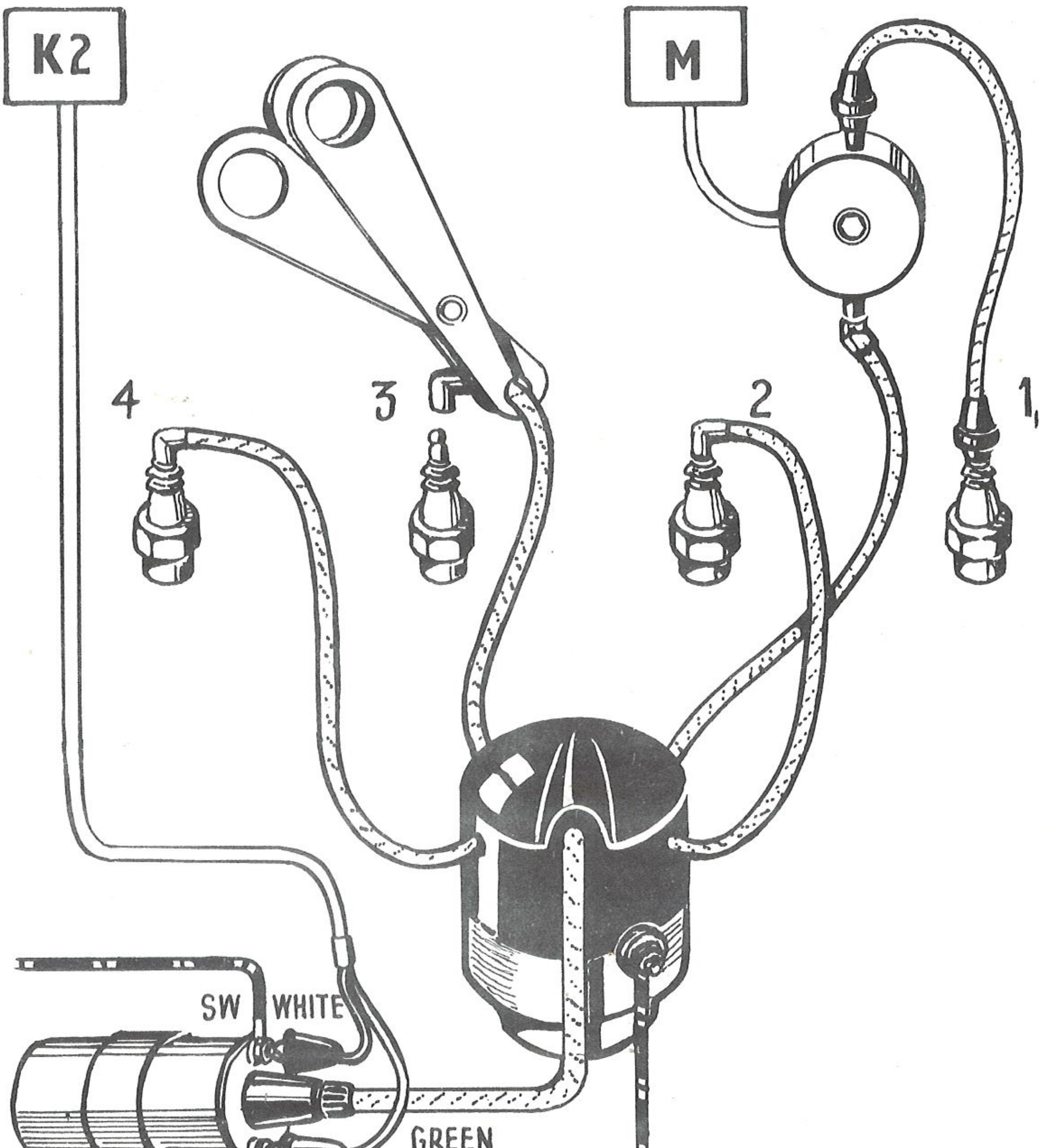

K2
M
4
3
2
1
SW
WHITE
GREEN
CB

FIG. 12 CONNECTIONS FOR TESTING IGNITION OUTPUT AND LEAKAGE

AREA TEST NO.5

IGNITION SECONDARY RESISTANCE AND COIL POLARITY

The fifth test in the Area Test Procedure completes the check of the ignition system and locates any loss of H.T. voltage due to high resistance. It also confirms that the polarity of the ignition coil connections is correct.

The circuits and components tested include the ignition coil polarity, the condition of the H.T. cable from the coil to the distributor; the coil H.T. connections; the distributor rotor and electrodes; the distributor pick-up brush; the High Tension cables; radio supressors and spark plug connections.

How to Make the Test

The same two ignition test leads are used as for the previous test, one lead being connected to the engine block and the other to each plug terminal in turn as Figure 13.

With the engine running at about 1,000 R.P.M. a control on the tester is adjusted until the meter reads in a mid-way position. The test lead is now connected to each plug in turn, when all plugs should give the same readings within close limits.

If the meter reads in the reverse direction, this indicates that the coil primary lead connections are reversed - they should be changed over.

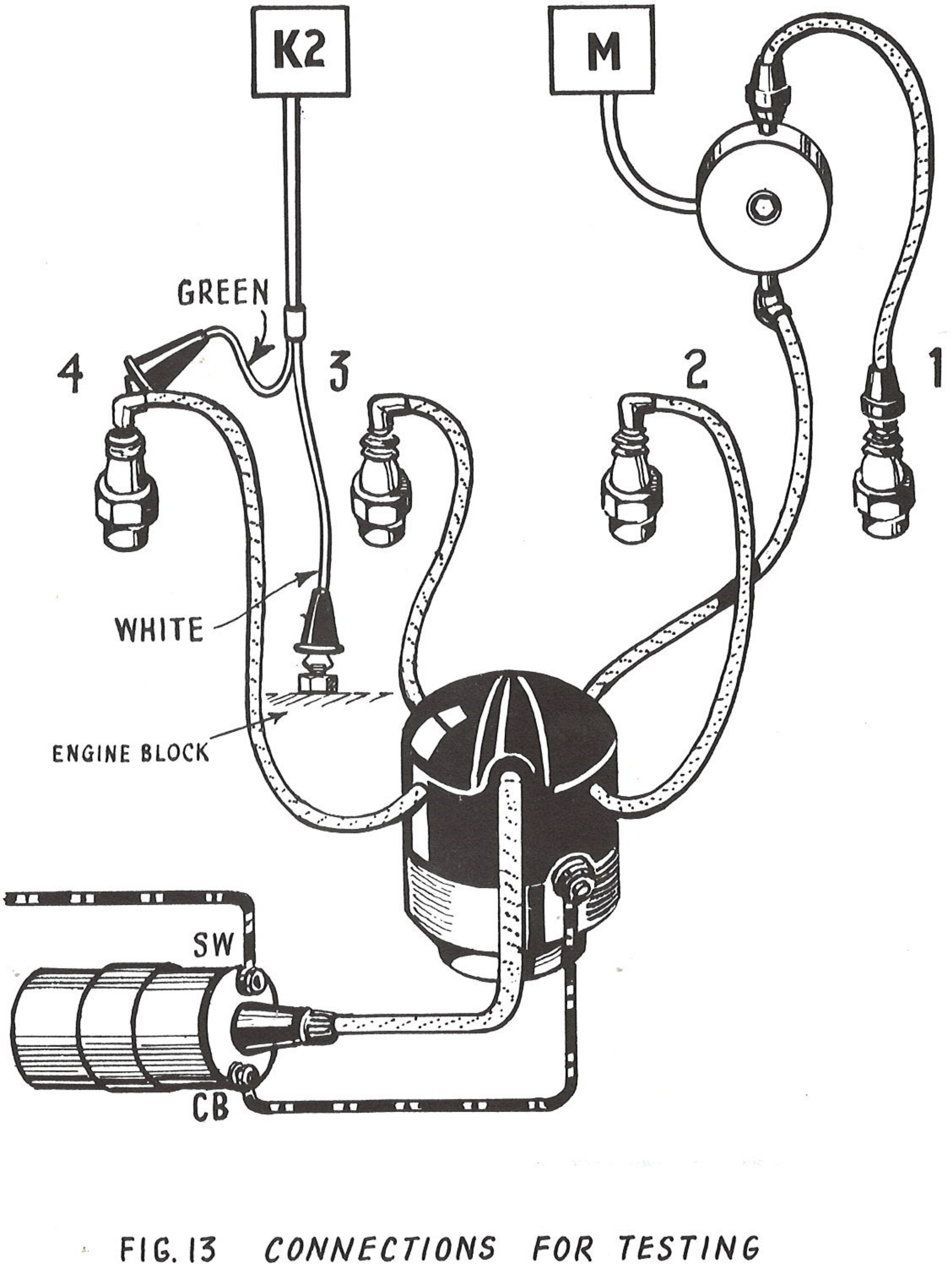

K2
M
GREEN
4
3
2
1
WHITE
ENGINE BLOCK
SW
CB

FIG. 13 *CONNECTIONS FOR TESTING IGNITION SECONDARY RESISTANCE*

AREA TEST NO.6.

CHARGING SYSTEM

The purpose of Test No.6 in the Area Test Procedure is to check the charging system and verify that all components, wiring and connections are in good condition and properly adjusted.

The test verifies that the voltage regulator, cutout and generator are in good condition, the battery free from high internal resistance and the connections from the generator to the battery are good.

How to Make the Test

The test is made by connecting the Voltmeter of the Tester to the ignition coil "SW" terminal and the cylinder block as shown in Figure 14. These connections apply to vehicles with positive earth return - if the negative terminal of the battery is earthed the connections should be reversed.

The engine is run at idling speed and the voltmeter readings carefully noted. It is important to note the exact reading within a fraction of a volt.

The engine speed is then momentarily increased when the voltmeter reading should rise. If this happens it shows that the charging system is operating satisfactorily.

If the voltmeter reading does not increase when the engine speed is raised it indicates the possibility of a defective generator or generator drive, incorrectly adjusted regulator or cutout, defective regulator or cutout or a high resistance in the charging circuit. The only effective way to deal with these possibilities is to make a separate test of the charging circuit, using a fully equipped Volt-Ampere Tester.

The test made does not actually check the voltage setting of the regulator. This can be done by inserting a piece of dry insulating material between the cutout points, connecting a voltmeter to the generator "D" terminal and earth and then measuring the voltmeter reading with the engine speed gradually increased. The reading should comply with the manufacturer's settings for the type of regulator tested.

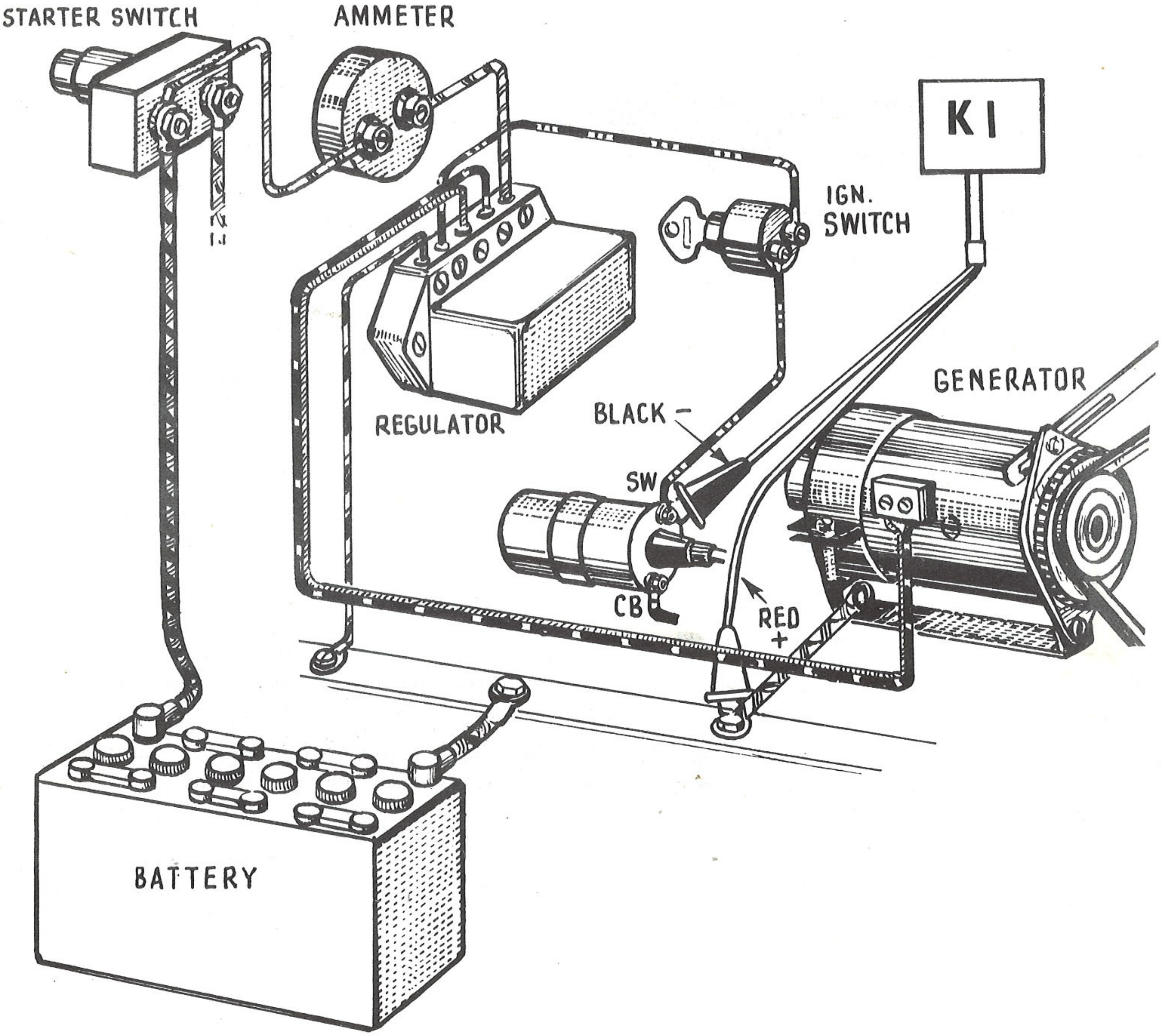

STARTER SWITCH
AMMETER
K1
IGN. SWITCH
REGULATOR
GENERATOR
BLACK –
SW
CB
RED +
BATTERY

FIG 14. *CONNECTIONS FOR TESTING CHARGING SYSTEM*

AREA TEST NO.7.

INDUCTION VACUUM AND ENGINE IDLE R.P.M.

The Area Test is completed by a measurement of engine induction vacuum which makes an overall check of engine efficiency and carburettor setting. An adjustment of the carburettor idle and the setting of the engine idle R.P.M. are usually included.

An engine in good performance condition will register a steady vacuum of 17 to 21 inches with a deduction of about one inch of vacuum per 1,000 feet for altitudes of 2,000 feet or more above sea level.

The vacuum reading is sensitive to irregularities in compression, carburettion and ignition and in the hands of an experienced operator, will give a reliable indication of many troubles such as ignition timing, compression, valve condition, air leaks, piston ring condition and carburettor and choke adjustment.

How to Make the Test

A test is made by connecting the vacuum gauge hose to any suitable point on the engine where vacuum can be obtained or to a central position on the intake manifold of the engine (Figure 15). If necessary the manifold is drilled and tapped, using a drill and taper tap smeared with grease. With the engine running at idle R.P.M. the carburettor idle screw is adjusted until a maximum steady vacuum reading is obtained. This should be between 17 and 21 inches and steady.

If the engine runs smoothly at the correct idle speed and if the vacuum reading is normal and steady, it indicates that the engine is in good condition with serviceable ignition and carburettion.

At the conclusion of the test the engine idle R.P.M. is set to 500/600 R.P.M. or to the vehicle manufacturer's recommended settings.

THIS COMPLETES THE STANDARDISED AREA TEST. THE RESULTS OF THE TEST SHOULD BE ENTERED ON THE REPORT FORM AS PREVIOUSLY ILLUSTRATED, INFORMATION BEING GIVEN ON THE FORM TO THE FURTHER ACTIONS NEEDED TO PROVIDE ANY CORRECTIVE SERVICE WHICH THE AREA TESTS HAVE DISCLOSED AS NECESSARY.

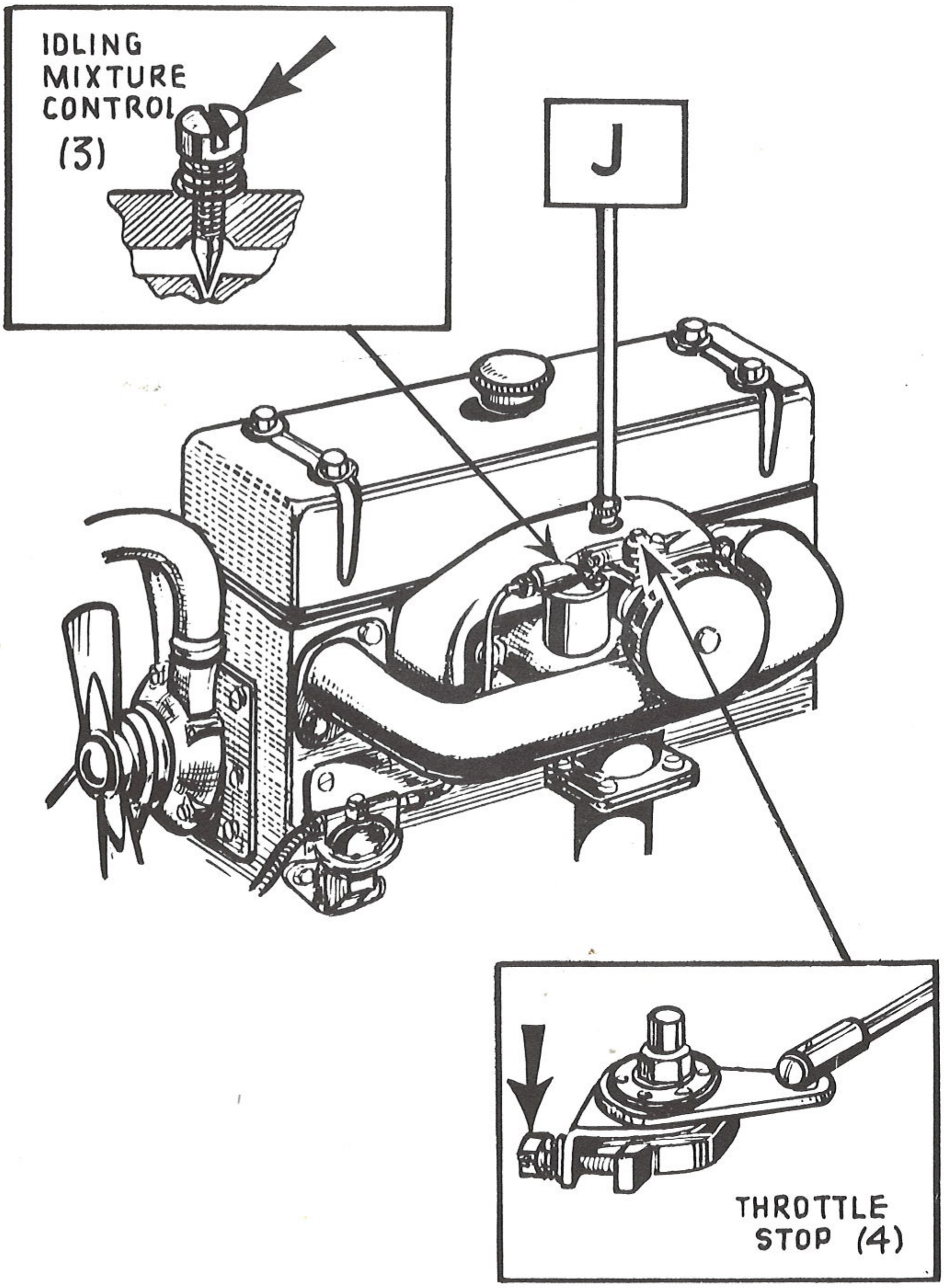

IDLING MIXTURE CONTROL (3)
J
THROTTLE STOP (4)

FIG. 15 *TESTING INDUCTION VACUUM*

SUPPLEMENTARY TESTS

Valuable supplementary tests can be made where conditions necessitate and give additional information of engine condition and performance efficiency.

TESTING CYLINDER BALANCE

This is a useful supplementary test which is made with the vacuum gauge and electric tachometer. It will often succeed - where other engine tests fail - in pointing to the cause of rough running or missing. The test gives a reliable indication of the power contribution of all cylinders and shows any cylinder or cylinders which are giving a lower output than others.

The test is made by connecting the vacuum gauge and the electric tachometer in the ordinary way and running the engine at 750 R.P.M. (4 cylinder) or 1000 R.P.M. (6 cylinder) or 1500 R.P.M. (8 cylinder). The connections are made as shown in the accompanying diagram, the master clip of the cylinder balance test unit being connected to the engine block and the individual test leads to all plugs except two cylinders. The engine is run on each pair of cylinders in turn and the engine R.P.M. and manifold vacuum noted for each pair of cylinders.

A variation of vacuum of more than one inch or a speed variation of more than 40 R.P.M. between pairs of cylinders indicates that the cylinders are out of balance. To insulate one weak cylinder half the cylinders in a straight line engine or one bank of a "V" type engine can be short circuited. The half - or the bank - giving the lower readings will include the weak single cylinder.

When making the test it is important to follow the correct firing order. This can be determined by dividing the firing order in half and putting one half over the other when the pairs of cylinders to be tested will appear one over the other.

If, for example, the firing order is 1-5-3-6-2-4, these are arranged as $\frac{1-5-3}{6-2-4}$ giving a testing order of 1-6, 2-5 and 3-4.

The usual sequences are as follows:-

4 cylinder engines: 1-4 and 2-3

6 cylinder engines: 1-6, 2-5 and 3-4

8 cylinder engines: (straight line) 1-8, 2-7, 3-6 and 4-5.

Ford "V8" engines: 1-6, 3-5, 4-7 and 2-8.

Testing Fuel Pumps

A test of the fuel pump is sometimes necessary to determine whether pressure or volume is low or high. If the pressure or volume is too low it will cause high speed missing because of insufficient fuel to the carburettor. If the pressure is too high, carburettor flooding will result, causing high fuel consumption and difficult starting.

The first test made is to check pressure and volume. This is done by disconnecting the fuel line of the carburettor and connecting the hose of the vacuum gauge to the fuel line. The engine is started and run on the fuel remaining in the carburettor bowl, and the reading on the pressure scale of the vacuum gauge carefully noted. If there is no reading it shows a defective pump or pipeline.

The engine is now switched off, when the meter should maintain running pressure. A fall-off indicates a leaking valve.

To test the volume of a pump a "T"-piece is fitted to supply fuel to the carburettor, permitting a pint of petrol to be collected in a graduated container. The average time needed to deliver one pint will depend on the displacement of the engine and will be about one pint in one minute for small engines, one pint in 45 seconds for medium engines and one pint in 30 seconds for larger engines.

A convenient test of the fuel pump is to measure the vacuum. This need not be done if the pressure and volume are both satisfactory.

To test fuel pump vacuum disconnect the inlet line to the fuel pump, insert a suitable adaptor pump and attach the vacuum gauge hose. With the engine at idle speed the vacuum gauge should be a minimum of 6 inches.

If the reading is less than 6 inches the trouble is probably in the pump and can be checked as follows:-

First stop the engine and reconnect the inlet line.
Then disconnect the fuel tank and attach the vacuum gauge to this fuel line. Now start the engine and repeat the test at idle speed, when the vacuum gauge reading should be at least 6 inches. If not, the trouble is due to air leaks or obstruction in the line between the tank and the fuel pump.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON II

PRACTICAL ENGINE DIAGNOSIS

How to Make a Systematic
Test of the Entire Engine

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

ENGINE DIAGNOSIS

Engine Diagnosis is the term applied to the complete process of search-testing all performance divisions of the engine to pinpoint the causes for lack of power, poor economy or unsatisfactory operation.

A diagnosis is an essential part of comprehensive engine performance servicing and should always logically follow an accurate area test carried out with such instruments as the Crypton "Motormaster" or "Powermaster" or B.1000 Engine Tune-up Bay. A Report Form should be completed, giving the results of the Area Test and this report form will determine the nature and extent of the further diagnosis tests necessary.

The connection between area testing and diagnosis is important and must be clearly understood. Both are necessary. Neither is complete without the other and for thoroughly efficient and fully profitable servicing both are needed.

AREA TESTING

Area Testing is the first step in engine performance servicing. Its purpose is to apply an "end-result" check on all factors which affect engine performance. It is applied to any vehicle brought in with a complaint of actual or suspected unsatisfactory engine or electrical performance. It is also applied for periodic tune-up as a means of testing the engine to confirm continued good performance or disclose any actual or developing performance deficiencies.

A series of seven area tests covers all possible causes of engine trouble in areas or sections of the engine and give a general picture of engine and electrical condition. When these tests show that all areas are satisfactory no detailed diagnosis is necessary, the vehicle needs no more than minor adjustments and tuning to achieve its full efficiency and performance. In cases, however, where the area tests show sub-normal indications in any one area, then a full diagnosis must be made of the circuits and components in that area to pinpoint the exact cause of low performance and enable the service needed to correct trouble to be accurately ascertained.

ENGINE DIAGNOSIS

Diagnosis can be termed "sharp focus" testing. Its basic purpose is to localise the exact circuits or components responsible for trouble or performance so that the necessary work can be carried out to restore normal performance and economy.

To be really effective diagnosis must be concentrated in sharp focus on the area in which faulty conditions have already been localised by the area test. The area test is therefore the guide to diagnosis and the information recorded on the area test report form indicates what tests are needed and which of the additional diagnosis instruments need to be used.

The accompanying illustration shows a special area test report form issued by Crypton. The layout of this form necessitates the minimum of writing by the operator but at the same time enables him to indicate that the seven area tests have been completed. This is done by inserting a "tick" in the "O.K."column or a "Cross" in the "service needed" column. When the form is opened it immediately discloses the further actions needed to pinpoint trouble in any area which has a cross against the "service needed" column, indicating the need of corrective service in a particular area of the engine.

EQUIPMENT FOR ENGINE DIAGNOSIS

Crypton manufacture a special instrument called the "Servicemaster" for engine diagnosis. Primarily designed for use in the service workshop, it contains the following individual testers and equipment:-

(1) Coil and Condenser Tester
(2) Exhaust Gas Analyser
(3) Tach-Dwell-Voltmeter
(4) Volt-Ampere Tester
(5) Vacuum Fuel Pump Tester
(6) Power Timing Light
(7) Cylinder Balance Tester
(8) Starter and Ignition Control Unit
(9) Accessories, including Insulated High Tension Pliers, Test Leads, Jumper Leads, etc.

A further valuable item of equipment is the Crypton Battery-Starter Tester. This is designed specifically for diagnosing faults in the battery and starting system. As with the other instruments, detailed above, it is housed in a portable cubicle and is complete and self-contained.

One of the components most frequently requiring servicing operations on modern vehicles is the distributor. Surveys show that nearly 50 per cent. of cars in operation require distributor servicing, ranging from cleaning and setting breaker points to complete reconditioning or replacement of the distributor. Crypton manufacture a specialised test bench which enables any competent mechanic to do complete distributor servicing quickly, easily and accurately. The test bench is self-contained, makes a comprehensive analysis of every distributor fault and enables exact adjustments to be made before distributors are refitted. The test bench operates on standard A.C. mains supply and is fully equipped for driving and testing all standard types of distributors.

HOW TO MAKE A SYSTEMATIC TEST OF THE ENGINE

For best results it is important to test trouble areas systematically, proceeding step by step through the entire area until the exact cause of trouble is pinpointed.

Battery and Starting Circuit Diagnosis

The most suitable instrument to use for diagnosing trouble in the battery and starting system is the Battery-Starter Tester. This has all the equipment required to make a comprehensive check of the battery, starter motor, starter switch and all wiring and connections.

First connect the Battery-Starter Tester to the vehicle battery, using the heavy current leads provided. Then adjust the carbon pile loading resistance until the ammeter reads three times the ampere hour rating of the battery. Thus, if the battery has an ampere hour capacity of 51 ampere hours, the carbon pile rheostat is adjusted until the ammeter reads 153 amperes. With the test voltmeter connected across the battery terminals the voltage at the end of 15 seconds should be not less than 9 volts for a 12 volt battery or 4.5 volts for a 6 volt battery. Readings higher than these figures show that the battery has adequate capacity for good starting service. Readings below these figures show that battery capacity is too low for continued satisfactory service. An independent cell test can be made by connecting the test voltmeter across each cell in turn. With the correct current load applied the voltage across each cell should be not less than 1.5 volts for 15 seconds.

Where the capacity test shows that the battery is below normal capacity, a test can be made using the Crypton Fast Charger. Instructions for doing this are given in an earlier lesson.

In cases where the battery is normally discharged, it can be quickly and safely re-charged with a Crypton Fast Charger and the test can be delayed until this is done. Alternatively, a replacement battery can be fitted. Where the tests show that the battery is defective, a replacement will obviously be essential. The charging of the battery or fitting a fully charged replacement will enable the area test to be repeated when the response of the starter will give an indication of its condition and the uniformity of engine loading. The starter must turn at a good rate of speed for a period long enough to give a good start. A check should be made for temperature rise in cable connections, starter switch, starter carcase and bearings and any undue sparking at commutator or brushes or noisy operation of the starter should be noted.

The Crypton Battery-Starter Tester can be used to verify the voltage drop across cable sections in the battery and starting system and in the earth strap of the battery and engine block. The 0-4 volt range of the Battery-Starter Tester voltmeter is used for this purpose. It is switched through independent test leads and the built-in carbon rheostat of the tester can be used to apply a supplementary load across the starter in cases where the engine is warm and light to ensure that the power absorbed from the battery is adequate for making a proper test of the starting system.

In some cases the area test report may indicate that the voltage at the ignition coil is low under normal stall-current load. In such cases the voltmeter of the Battery-Starter Tester can be used to check the voltage drop in the ignition primary system. This is done by connecting the test voltmeter at various points throughout the system until the point of high voltage loss is located.

Where the starter is reported to be erratic or fails to respond to switch operation the trouble may be due to a defect in the solenoid switch control circuit. The voltmeter of the Battery-Starter Tester can be used to test the voltage drop across the wiring connections and starter button switch of this control circuit.

The tests made will reliably disclose any fault in the battery which prevents its developing sufficient starting ability and also in the entire starting system, other than in the starter itself. Where the tests indicate that the trouble is in the starter it must be removed for bench tests or replacement.

TESTING DISTRIBUTOR

If Test No.2 in the area test procedure shows deficiencies in the distributor resistance, or dwell angle, a detailed diagnosis can be made by using a Tach-Dwell-Voltmeter. Either the instrument on the Area Tester or the "Servicemaster" or a Portable Tach-Dwell-Voltmeter can be used for this purpose.

First make a detailed inspection of the wiring and connections in the distributor circuit. This includes all tag connections and solder junctions which should be thoroughly inspected for possible causes of high resistance. A test must be made with the distributor points closed and current flowing and voltmeter leads should be connected across the following points:-

Voltage drop across closed distributor contacts.

Voltage drop across contact of adjustable contact mounting and distributor base.

Voltage drop across contact of base and distributor body.

Voltage drop between distributor body and engine block.

Distributors with integral vacuum advance units operated on movable base plates should be checked for the connection of linking flexes which earth the body to the base.

It will often be found that high resistance in the distributor circuit originates in a simple dirty connection which can be immediately corrected; a repeat test will show that the cause of the trouble has been eliminated by the reduction of voltage loss obtained.

Where the area test discloses that the dwell angle of the distributor is outside specified limits, the Tach-Dwell Voltmeter can be used to ascertain the cause. The first check should be to carefully adjust the distributor contact breaker gap in accordance with the manufacturer's settings. A repeat test should then be made of the angle of dwell, repeating the procedure employed in the area test.

If the dwell angle on re-test remains high or low, the corrective procedure depends largely on the degree of accessibility of the distributor. Unless the contact breaker and cam can be closely inspected, it is desirable to remove the distributor so that a complete test can be made in the Crypton Distributor Tester. This tester enables the distributor to be mounted and run as on the vehicle and is fitted with full means of checking phase angles, cam angle, auto-advance and general performance. Such frequent troubles as irregular dwell, dwell angles outside the specification or excessive variation of dwell angle between idle and high engine speed can be quickly and accurately located and the exact cause of trouble such as cam lobes, rocker heel, spindle or bearings immediately assessed.

Diagnosing Auto-Advance and Ignition Timing Deficiencies.

Where Area Test No.3 shows deficiencies in ignition timing and automatic advance operation, a systematic diagnosis can be employed to pinpoint the cause of trouble. This may require the removal of the distributor for a complete check in the Crypton Distributor Tester.

Ignition timing, if found incorrect, can be adjusted on the vehicle by releasing the distributor clamp and turning the body of the distributor to bring the timing marks into line.

Incorrect auto-advance readings can be due to a number of mechanical defects such as stiffness or lack of lubrication of the cam sleeve and spindle, incorrect springs, improperly assembled linkage, wear of limit pegs and other causes. Testing on the Crypton Distributor Tester will confirm the error and show how far it may be possible to correct the trouble by shop servicing or if it will be more satisfactory to fit a replacement distributor.

The tests made with the Distributor Tester are much more searching than can be applied on the vehicle. The distributor can be run at speeds in excess of those at which maximum advance is attained, enabling the limit of spring action to be verified and the extent of wear in stops, etc. to be accurately checked.

At the same time a confirmatory check of the insulation of the distributor cap and rotor can be made, for which purpose the integral coil of the distributor tester is used in conjunction with the spark gap provided.

A Distributor Tester also enables the practical functioning of the condenser to be observed, because the distributor can be run at any speed with the cap and rotor removed so that sparking at the contacts can be visibly checked.

An important test made by the Distributor Tester is to check the vacuum advance against the manufacturer's specified vacuum. This is done by the use of a test pump and gauge incorporated in the distributor tester, which enables the extent of advance resulting from a given applied vacuum to be observed on a protractor scale which shows the actual shift of spark pattern. After testing and servicing the vehicle distributor or fitting a replacement, a Power Timing Light is employed to set the ignition timing in accordance with the manufacturer's settings. The Timing Light also confirms that no distortion or stress has been introduced in the refitting and when used in conjunction with the Auto-Advance Tester, enables the final automatic advance readings to be accurately assessed.

DIAGNOSING CAUSES OF LOW IGNITION OUTPUT AND LEAKAGE.

Test No.4 in the Area Test Procedure checks the ignition system for output and leakage. The purpose of the area test is two-fold. Firstly to measure the reflex voltage induced in the coil primary winding when the secondary winding is open circuited. This is a practical check of the condition of the ignition coil and condenser. The second purpose of the test is to ascertain if there is any significant leakage of H.T. energy taking place through the insulation of the H.T. cables to distributor cap and rotor; as each H.T. cable is disconnected during the test the voltage surge as the rotor reaches the electrode of the cylinder concerned is applied to the insulation.

If, when making the test, a low reading is obtained on all cylinders, this implies a general loss of ignition efficiency which is not peculiar to any one cylinder. It may be due to low performance of the ignition coil, condenser, to deficiencies in wiring or connections or poor contact breaker points.

The first check should be made of the distributor breaker points by measuring the voltage drop across the points as explained in earlier lessons.

Next check the ignition coil and condenser with a Coil and Condenser Tester such as the Crypton B.62 combined Coil and Condenser Tester. This instrument operates from a battery of the same voltage as the coil to be tested. It tests the performance of the coil against pre-determined figures given in a test chart which are based on the performance of an equivalent new coil. The test covers a check of the resistance of the coil primary winding, a continuity check of the secondary winding and an output power test of the coil under working conditions. The instrument also makes an independent test of condensers, making a measured test of the two important factors of series resistance and capacity, both of which can be checked against the maker's specification.

If the results of the area test show a low reading on one cylinder, it indicates immediately that the fault is localised and not due to coil or condenser or to any general cause.

First check the contact breaker gap on each cam lobe, paying special attention to the gap and timing on the cylinder concerned.

Then apply an H.T. search test to the cable and distributor insulation and carefully check the electrode gap and cable connections.

DIAGNOSING CAUSE OF LOSS OF H.T. OUTPUT AND ADJUSTING COIL POLARITY.

Test No.5 in the Area Test Procedure is largely confirmatory of the previous ignition test with the additional check of working high tension voltage at the spark plug terminals under operating conditions. The test also indicates the polarity of the spark. This is an important test on modern engines because the electrons which form the spark will be greater when the centre electrode of the plug is negative than when it is positive. If the plug polarity is reversed this will be indicated by a reversed reading of the test meter. With certain special exceptions it is then advisable to change over the primary connections at the ignition coil.

In making the area test the meter reading is adjusted to the "Set" position for the number of engine cylinders and a comparative reading obtained for all other cylinders with the engine running at 1,000 R.P.M. The first cylinder - on which the adjustment of the reading is made - is therefore the reference reading.

A general low output due to a basic ignition trouble is indicated by difficulty in obtaining the set reading on the reference cylinder with the same difficulty on other cylinders. If any cylinder shows a higher reading than the reference reading the reference cylinder selected may be low in output.

If a general low reading is experienced it is necessary to make a detailed check of the ignition coil, condenser, distributor contact breaker, wiring and connections as already described.

If a low reading on any one plug is experienced, this may be due to excessive resistance in the H.T. path; a check should be made of cable connections and the electrode gap. The use of radio suppressor resistors influences the output readings and where suppressor type H.T. cables are fitted it will be found that lower readings occur on cables of greatest length.

A conductive path across the spark plug insulator will also cause a lower reading. This should have been eliminated by the previous cleaning and testing of plugs during the area test. A check, however, should always be made in cases where the output readings are low and there is no unequality in the H.T. circuit section concerned, by comparison with other sections.

DIAGNOSING CHARGING SYSTEM

The purpose of Test No.6 in the Area Test Procedure is to make a quick check to ascertain if the charging system is performing normally. This is indicated by a rise in battery voltage as the engine is speeded up, proving that the generator is operating and that charging current is flowing in the battery. If there is no voltage rise when the test is made the reverse is the case and a diagnosis must be carried out to ascertain the reasons for non-charging.

The instrument used for this test is the Crypton "Electromaster" which is specially designed for making a comprehensive test of the charging system of any 6, 12 or 24 volt equipped vehicle. The test should be made in accordance with the detailed instructions given with the instrument.

Before making electrical tests an inspection should be carried out of the generator belt and pulleys, wiring, connections and the charging system as a whole. The generator belt and pulley should be checked for wear and correct tension, paying special attention to the condition of pulley faces and belt sides where frictional wear is greatest. Carefully inspect all wiring and see that connections are clean and tight. Check the cutout, generator connections and where possible inspect generator, commutator and brushes.

The test procedure should follow the maker's recommendations and information is given in the Crypton "Electromaster" manual of how to do this for all standard makes of electrical systems such as Lucas, Autolite and Delco-Remy. Further information is also given in the Lesson dealing with electrical diagnosis.

DIAGNOSING CAUSE OF IRREGULAR VACUUM READINGS

The final test in the Area Test Procedure is a check of engine induction vacuum. In this test the indications of induction manifold vacuum are observed, giving a general reflection of mechanical condition, ignition operation, carburettion and the volumetric efficiency of the engine. In this connection it should be noted that any possible ignition factors influencing the vacuum gauge reading have been eliminated by the previous detailed tests made of the ignition system.

Of all the instruments used in engine testing, the Vacuum Gauge is responsive to the greatest number of performance factors. It indicates the effect of almost any factor such as late ignition timing, or valve timing, compression deficiencies, ignition irregularities and maladjustment of the carburettor. Whilst this excellent sensitivity to performance factors is a very useful feature in itself, it leaves open the possibility of misconception of the vacuum gauge readings because various performance factors have a generally similar effect. It is for this reason that the vacuum test is deferred until all ignition tests have been completed and compression conditions verified so that the possible field of influence on the vacuum gauge is narrowed down and we can relate vacuum indications with a known group of facts.

During the area test, vacuum readings were checked under three conditions, namely,

(1) Starter Vacuum Test. In this test a measurement is taken of the vacuum created in the manifold with the throttle closed and the starter turning the crankshaft. This primarily checks the air tightness of the manifold, carburettor joints, etc. At the same time, however, it is a useful check of air leakage in the cylinders past worn piston rings and valves. In other words, it is a check of the pumping function of the engine and proves efficient induction.

(2) Cylinder Balance Test. This check shows the degree of power contribution of all engine cylinders. With the engine running at 1,000 R.P.M. the plug lead is lifted from each plug terminal in turn. This puts the cylinder concerned out of action and the speed and therefore the mean vacuum falls. The extent of the fall in vacuum clearly shows the proportion of power contributed by the cylinder. A cylinder producing full power will show a relatively large drop in vacuum; a cylinder producing a weaker power impulse will cause a lower drop in vacuum. Therefore, any cylinder which gives a low fall in vacuum is not contributing its full power.

(3) Average Vacuum Reading. This is a general check of engine efficiency by measuring the mean vacuum with the engine idling. A healthy engine in good condition should give a steady reading of 17 to 22 inches of vacuum. In practice the test reflects mainly the setting of idling mixture because ignition and compression have already been checked and the quality of cylinder power output measured.

Area testing also gives a general indication of carburettion conditions. Normally, the idling mixture is set during the area test to obtain the highest steady vacuum at a fixed idling speed.

To make a more detailed diagnosis of carburettion it is necessary to use an Exhaust Gas Analyser. This gives a visual indication of the remaining carburettor phases - jet transfer on acceleration, compensation and power jet response. The Exhaust Gas Analyser shows the effect of mixture changes over the whole power and speed range and the action of the accelerator pump, vacuum-actuated jet control or other special features of the carburettor concerned is reflected in the change of instrument readings from lean to rich or the reverse. The effect of any adjustment or correction made in accordance with the maker's data for the vehicle concerned can be immediately checked.

When diagnosing the carburettion system it is often necessary to check the cause of irregularities in fuel delivery to the carburettor due to faulty pump or fuel pump line. These troubles can be analysed by the use of the fuel pressure gauge of the combination Vacuum Gauge. Suitable adaptors are provided and both the pressure and volume of the pump can be measured and checked against manufacturer's data.

A final check of the engine can be made by observing the vacuum gauge response to acceleration and deceleration. The whole passage of air and gas through the engine, from the air cleaner to the exhaust output (generally included in the term "breathing") has a profound effect on engine performance and it is important that this function should be checked in a complete diagnosis. The performance of the vacuum gauge on acceleration and deceleration will give a valuable indication of the efficiency of the engine's "breathing" action.

Various accessories are supplied with Crypton test equipment which simplify and speed up the many useful tests which can be made with a Vacuum Gauge. These include a special Cylinder Balance Tester which enables cylinders to be cut out in alternate firing order, thereby testing under load conditions the power developed in the remaining cylinders. A special Starter and Ignition Control provides a means of switching on or off and operating a solenoid controlled starter from a remote position. This enables the mechanic, while working under the bonnet, to start and stop the engine as required.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 12

PRACTICAL ELECTRICAL DIAGNOSIS

How to make a Systematic
Sequence Test of the Vehicle
Electrical System.

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

SYSTEMATIC ELECTRICAL DIAGNOSIS

In previous Chapters we have considered the individual components which make up the complete vehicle system. In the present Chapter we deal with the system as a whole, and consider the simplest and best procedure for maintenance testing and for the location and correction of any troubles or defects that develop.

The most effective way of testing the electrical system in its entirety is to follow an orderly method of elimination testing. Starting at the battery, the complete system is tested, step-by-step, eliminating one possible cause of trouble after the other, until the entire system has been tested. This is both easier and quicker than disorderly testing. The same method can be used for maintenance service, where the system is checked to ensure its continued good performance and for the location of causes of impaired performance.

TESTING EQUIPMENT NEEDED.

Two instruments are needed for electrical diagnosis, a high quality moving coil voltmeter and an ammeter. The voltmeter ranges needed are 0-1, 0-10, 0-20 and 0-50 volts. Suitable ammeter readings are 10-0-50 amperes and 20-0-100 amperes which can be provided on the same instrument. External shunts can be used with the ammeter and enable higher current readings to be obtained.

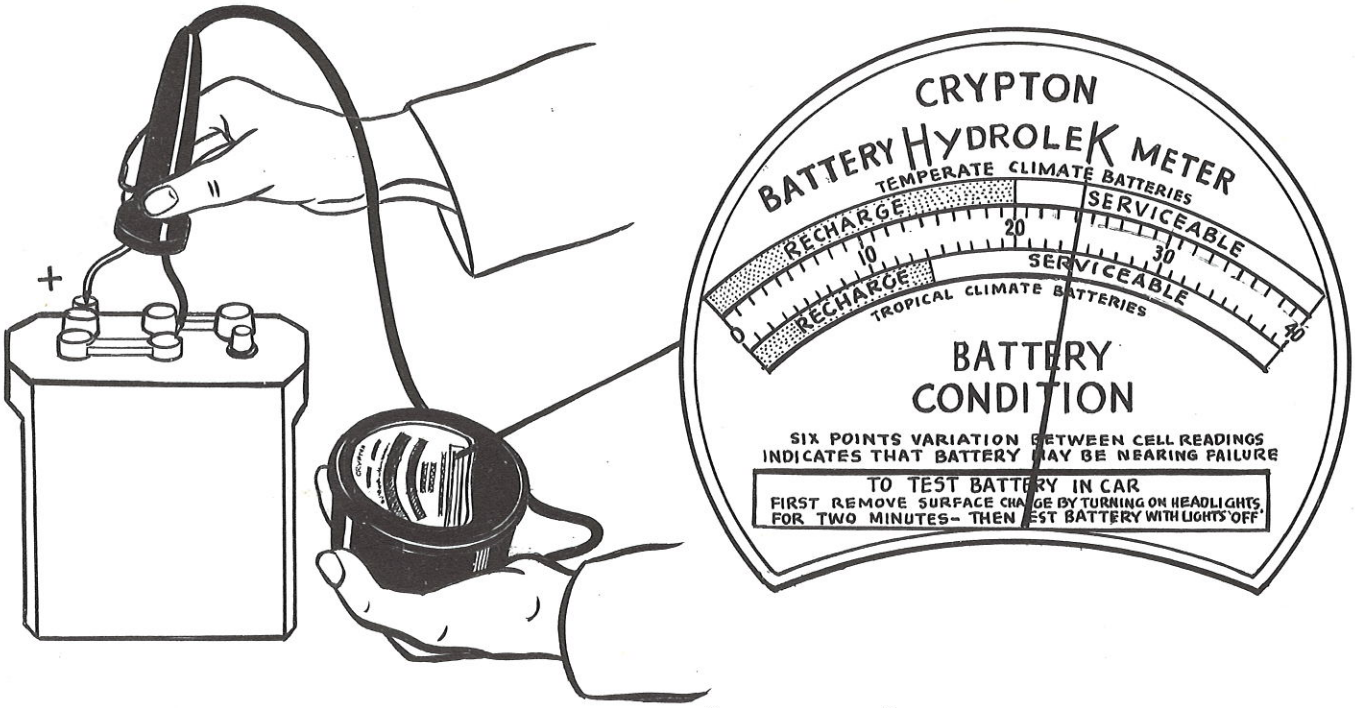
Instruments for electrical diagnosis must be of high quality standards. Electrical units are precision built and for satisfactory operation, must be maintained within close tolerances. Voltmeters with an error of more than 1 per cent. may cause regulators to be incorrectly adjusted. Ammeters must be accurate within 2 per cent. Always keep your standards of accuracy high, by doing so you will safeguard both your work and your reputation.

SEQUENCE TESTING.

The most satisfactory principle of electrical diagnosis is to apply a process of systematic sequence tests which eliminate one possible cause of trouble after the other. Both vehicle electrical equipment and test equipment manufacturers have developed standardised methods of sequence testing which enable a routine test to be made of the vehicle electrical system, both for maintenance and trouble-shooting purposes. The test sequence follows a generally similar pattern, commencing with the battery, proceeding through the starter, then testing the generator and completing the tests with a check of the voltage regulator and complete circuit resistance.

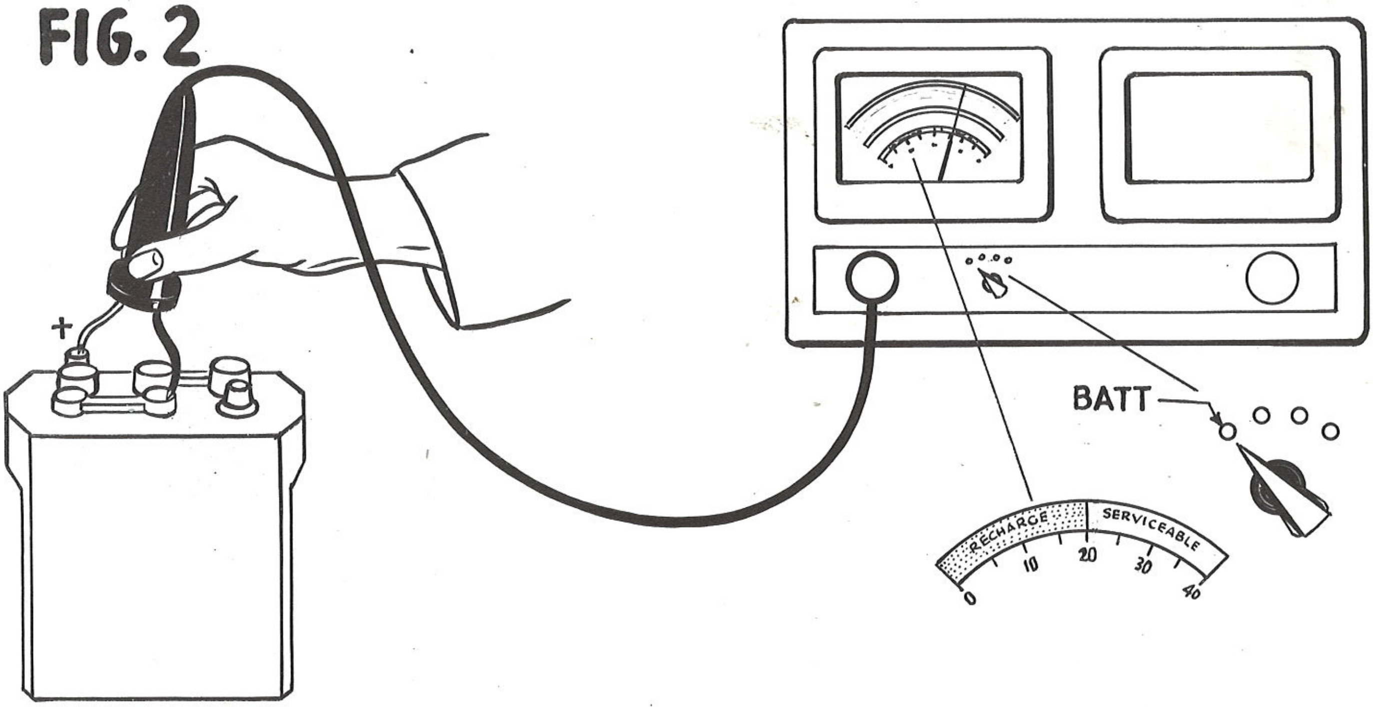
The procedure explained in this Lesson has been found to be a very simple and practical way of carrying out a routine diagnosis and if carefully followed, will produce accurate results in the minimum of time.

FIG. I TESTING BATTERY STATE OF CHARGE


+
CRYPTON
BATTERY HYDROLEK METER
TEMPERATE CLIMATE BATTERIES
RECHARGE
SERVICEABLE
0
10
20
30
40
RECHARGE
SERVICEABLE
TROPICAL CLIMATE BATTERIES
BATTERY CONDITION
SIX POINTS VARIATION BETWEEN CELL READINGS INDICATES THAT BATTERY MAY BE NEARING FAILURE
TO TEST BATTERY IN CAR
FIRST REMOVE SURFACE CHARGE BY TURNING ON HEADLIGHTS FOR TWO MINUTES- THEN TEST BATTERY WITH LIGHTS 'OFF'

TESTING BATTERY STATE OF CHARGE WITH "HYDROLEK" BATTERY CHARGE METER

FIG. 2


+
BATT
RECHARGE
SERVICEABLE
0
10
20
30
40

TESTING BATTERY STATE OF CHARGE WITH BATTERY TEST SCALE OF VOLT AMPERE TESTER

TESTING THE BATTERY

Every electrical diagnosis job should start with the battery. This is the starting point of the electrical system. For good engine performance the battery must be in good mechanical condition and be capable of satisfactory electrical performance. Three tests are needed to verify this:-

(1) A careful inspection of the battery.
(2) A check of battery state of charge.
(3) A test of battery capacity.

PRELIMINARY.

Before testing the battery, an inspection should be made of the generator fan belt and pulleys, the condition of which influence the generator charging rate and consequently the battery state of charge. The belt must be free from excessive wear, properly positioned in the pulleys and correctly tensioned; all pulleys must be in good condition.

BATTERY INSPECTION.

Check the battery carefully for condition of terminals and connections, terminal posts, stoppers, lids, sealing, inter-cell links, case condition and level of electrolyte. Consult Figure 11 and information on Page 10 in Lesson 2 for further details.

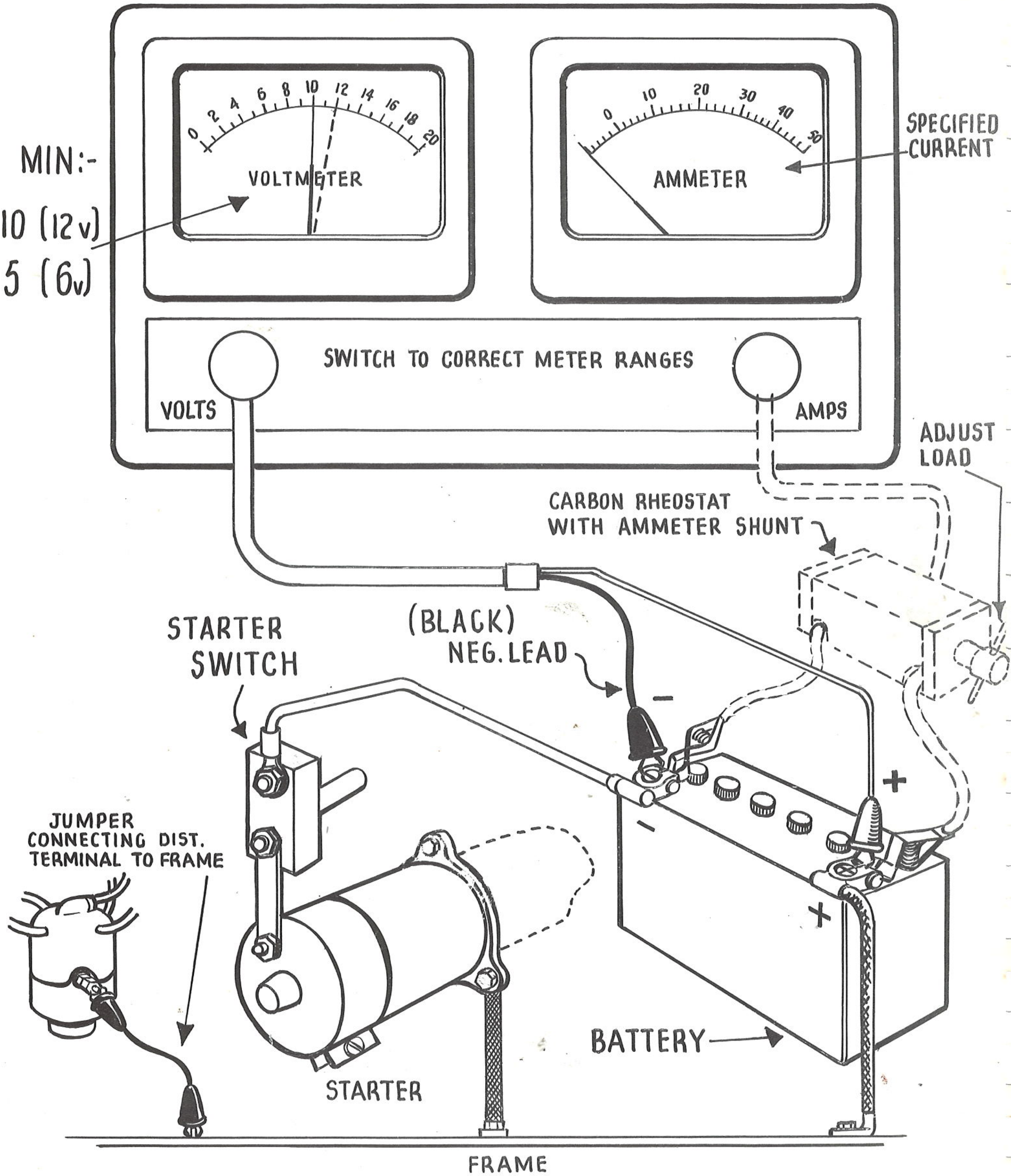
TESTING BATTERY STATE OF CHARGE - (FIGURES 1 AND 2).

The latest and best method of testing the state of charge of a battery is with an open circuit voltage tester or Battery Charge Meter. This is an electrical substitute for the Hydrometer and comprises a special type of expanded scale voltmeter which shows the battery state of charge in terms of cell open circuit voltage. The instrument has scales zoned "SERVICEABLE" and "RECHARGE". Any cell insufficiently charged for good service will read in the "RECHARGE" zone and cells which are in normal charged condition in the "SERVICEABLE" zone.

The Battery Charge Meter is quicker to use and comparable in accuracy with the Hydrometer. One of its advantages is that tests can be made when the electrolyte level is too low for hydrometer testing. The main use of the Battery Charge Meter is for testing batteries on the car; it cannot be used for testing batteries during charge. The test can be made either with a separate meter as shown in Figure 1 or with the Crypton Volt-Ampere Tester which has an open circuit voltage scale incorporated in the instrument readings. When the battery has been charged immediately before testing, such as when a vehicle is brought in from the road, the headlights and other load should be switched on for one minute before the test is made. This dissipates the abnormal high voltage of the battery as a result of charging. When testing a battery just after it has been discharged, it should be allowed to stand for some time until normal voltage is reached.

The tests are made by connecting the instrument prods across each cell in turn, when the condition of the cell will be immediately indicated by the instrument reading. If all cells read in the "SERVICEABLE" zone and are balanced within six points, the battery is in good condition.
If all cells read in the "RECHARGE" zone and are in balance within six points, the battery needs recharging.
If any cell or cells reading in the "SERVICEABLE" or "RECHARGE" zone are six points or more lower than others, it indicates the possibility of a battery defect. The battery should be removed, recharged and re-tested for both state of charge and capacity.

FIG. 3. BATTERY CAPACITY TEST


MIN:-
10 (12v)
5 (6v)
0 2 4 6 8 10 12 14 16 18 20
VOLTMETER
0 10 20 30 40 50
AMMETER
SPECIFIED CURRENT
SWITCH TO CORRECT METER RANGES
VOLTS
AMPS
ADJUST LOAD
CARBON RHEOSTAT WITH AMMETER SHUNT
STARTER SWITCH
(BLACK) NEG. LEAD
−
+
−
+
JUMPER CONNECTING DIST. TERMINAL TO FRAME
STARTER
BATTERY
FRAME

TESTING BATTERY CAPACITY.

A load must be applied to determine whether the battery has adequate capacity to give good starting service. Three methods are available to carry out this test, as follows:-

(1) HIGH RATE DISCHARGE TEST.

This test is made with a High Rate Discharge Tester which consists of a Voltmeter with a resistance load of about 150 amperes connected in parallel. The Voltmeter with its parallel load is connected across each cell for fifteen seconds, after which all cells should read 1·5 volts or more, uniform within 1/10th volt. The test indications obtained are approximate only because the same load is applied to cells of various capacities. For fully accurate results the load should be adjusted according to the capacity of the battery.

(2) VARIABLE DISCHARGE RATE CAPACITY TEST.

This method uses a variable rheostat with an ammeter and voltmeter, the connections being shown in Figure 3. The voltmeter is connected across the battery posts and the ammeter with a carbon pile rheostat in series is also connected across the same battery posts.

The carbon pile rheostat is adjusted until the ammeter reads the discharge current to be applied. This should be two times the ampere-hour capacity of a 6-volt battery and three times the ampere-hour capacity of a 12-volt battery. Thus, for testing a 75 ampere-hour battery, the current load would be adjusted to 150 amperes and for a 56 ampere-hour 12-volt battery, to 168 amperes.

The load is applied for fifteen seconds, at the end of which the voltage across the battery is read. If the voltage is not less than 9 volts for a 12-volt battery or 4·5 volts for a 6-volt battery, the capacity of the battery is adequate for continued good service.

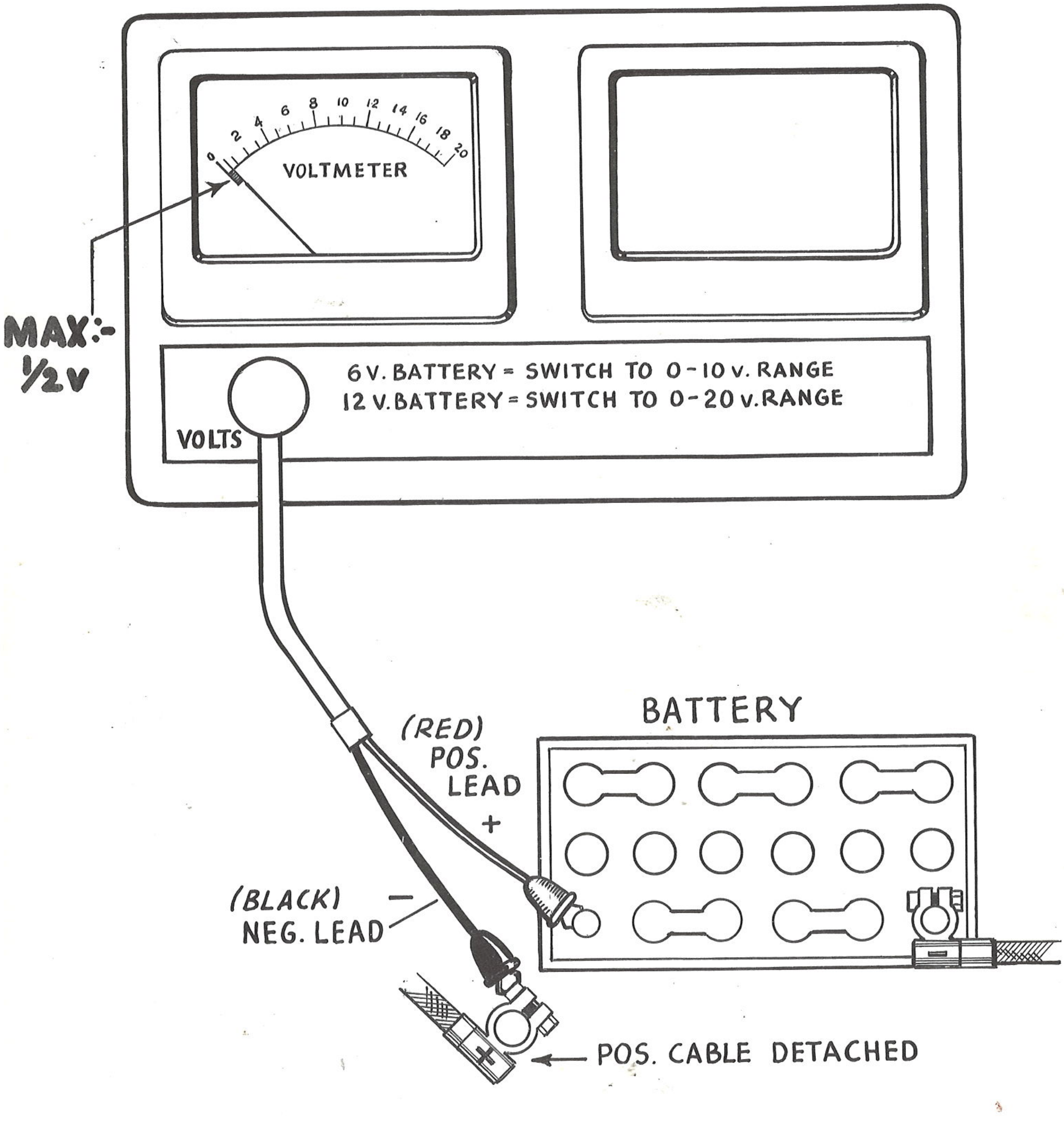
(3) STARTER LOAD METHOD.

Instead of using a variable resistance, the starter itself can be used to load the battery. The engine must, however, be cold when making this test, a warm engine will not simulate service starting conditions - its load will be too light.

The connections for making the test are shown in Figure 3, the ammeter and carbon pile rheostat connections being eliminated. A jumper should be connected between distributor "CB" terminal and "Earth".

With the starter cranking the engine (ignition off) a battery voltage of 10 volts for a 12-volt battery or 5 volts for a 6-volt battery indicates that the battery has adequate capacity for continued good service.

FIG. 4 BATTERY CURRENT LEAKAGE


0
2
4
6
8
10
12
14
16
18
20
VOLTMETER
MAX:-
½V
VOLTS
6 V. BATTERY = SWITCH TO 0-10 v. RANGE
12 V. BATTERY = SWITCH TO 0-20 v. RANGE
BATTERY
(RED)
POS.
LEAD
+
(BLACK)
NEG. LEAD
−
+
POS. CABLE DETACHED

BATTERY LEAKAGE - (FIGURE 4).

The purpose of this test is to check if there is any excessive leakage of current from the battery due to acid-soaked dirt, causing a current leakage to earth or the leakage of current through defective insulation in the wiring and switches. The accumulation of dirt on the top of the battery absorbs electrolyte and becomes a conductor. It slowly drains the current away causing the battery to become discharged which allows a battery to run down and causes starting difficulties.

PREPARATION.

Before making the test, note which battery terminal is connected to Earth. If this is the POSITIVE terminal the system is POSITIVE EARTH RETURN. If the NEGATIVE battery terminal is connected to earth, the system is NEGATIVE EARTH RETURN.

Most modern systems are of the Positive Earth Return type and all the diagrams in this chapter are based upon this assumption. If the vehicle is of the Negative Earth Return type, the connections shown should be reversed.

ADJUSTMENT.

Adjust the Test Set to suit the system voltage by setting the Voltmeter switch as follows:-

For 6-volt systems, set Voltmeter switch to "10V" position.
For 12-volt systems, set Voltmeter Switch to "20V" position.
For 24-volt systems, set Voltmeter switch to "50V" position.

CONNECTIONS.

Remove the positive clamp from the terminal post of the battery and clean it. Connect one voltmeter lead to the clamp and the other voltmeter lead to the terminal (which should also be cleaned).

TESTING.

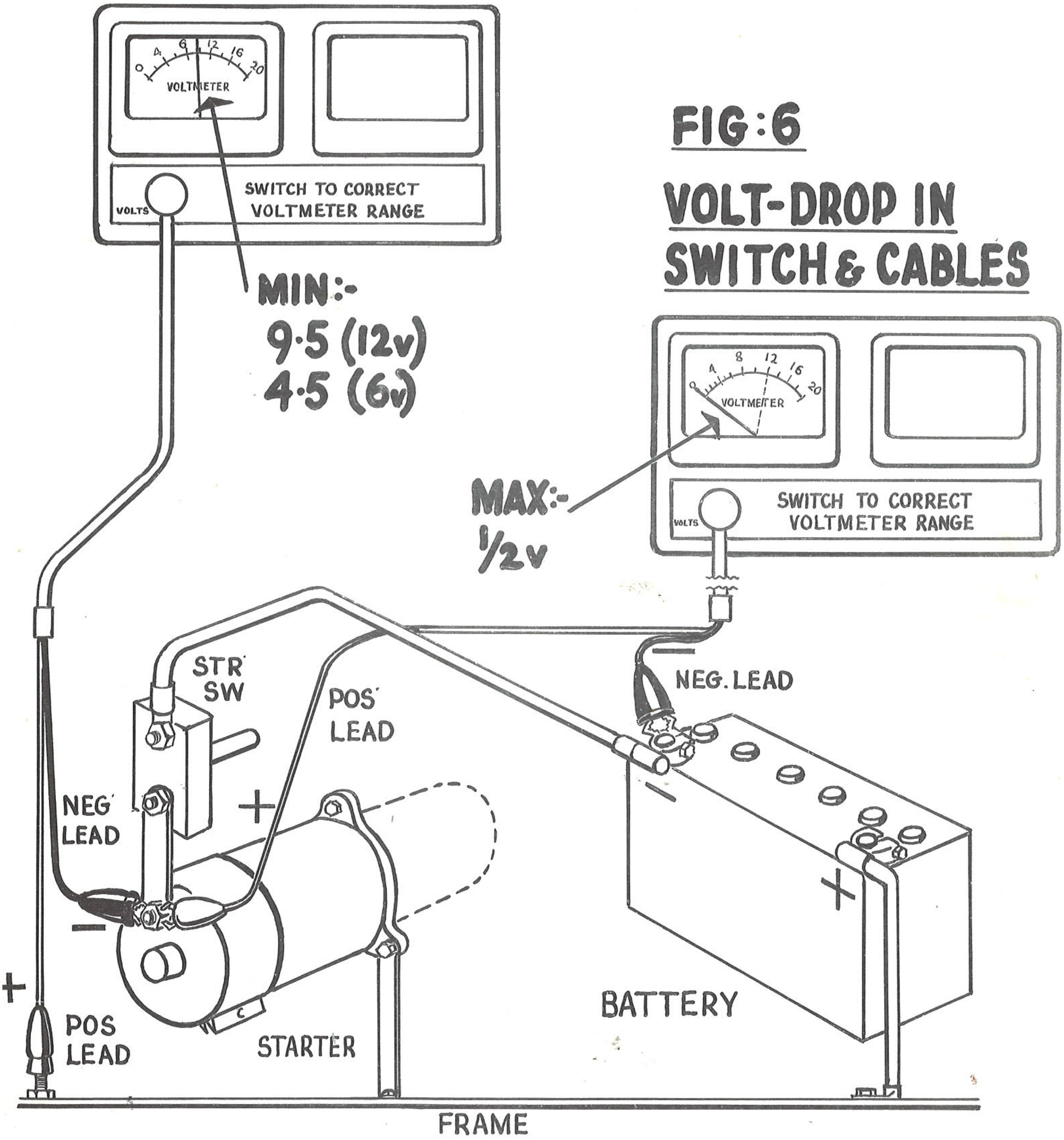
With all switches off, the voltmeter will indicate the extent of any leakage of current from the battery. For ideal conditions there should be no leakage but a slight leakage is permissible, indicated by a voltmeter reading not more than ½ volt.

If there is a reading higher than ½ volt, the battery case should be cleaned, and dried, and the test then repeated. If the reading is still higher than ½ volt, it shows that the trouble exists outside the battery due to leaky insulation of wiring, switches or components. The further tests made in the systematic test of the vehicle system will help to locate the cause of the trouble.

FIG:5 VOLTAGE AT STARTER

FIG:6

VOLT-DROP IN SWITCH & CABLES


0 4 8 12 16 20
VOLTMETER
VOLTS
SWITCH TO CORRECT VOLTMETER RANGE
MIN:-
9·5 (12v)
4·5 (6v)
0 4 8 12 16 20
VOLTMETER
VOLTS
SWITCH TO CORRECT VOLTMETER RANGE
MAX:-
1/2v
STR SW
POS LEAD
NEG. LEAD
NEG LEAD
+
−
−
+
POS LEAD
C
STARTER
BATTERY
+
FRAME

STARTER CIRCUIT TESTS

TESTING STARTER CIRCUIT VOLTAGE.

The starter cannot be tested against manufacturer's specifications in position in the vehicle, but its general performance can be checked and the circuit tested for excessive resistance. When making the test the starter is used for cranking the engine and to prevent the engine starting on certain models of vehicles, the distributor primary terminal should be connected to earth.

TESTING THE VOLTAGE AT THE STARTER - (FIGURE 5).

The purpose of this test is to verify that normal voltage is available at the starter terminal. If, having previously tested and proved the condition and capacity of the battery, the voltage at the starter is lower than normal, it shows excessive resistance in the circuit between the battery and the starter.

With a Voltmeter connected as shown in Figure 5, the engine is cranked and if the voltmeter reading is 9·5 volts or over for a 12-volt system or 4·5 volts or over for a 6-volt system, the cables and connections are satisfactory.

TESTING VOLT-DROP IN STARTER SWITCH AND CABLES.

This test confirms the previous test by directly measuring the volt-drop between the battery and starter terminals.

The connections are shown in Figure 6, the Negative voltmeter lead being connected to the battery live Negative terminal and the Positive lead to the starter terminal. These connections apply to Positive Earth Return systems - for Negative Earth Return Systems, the voltmeter connections are reversed.

With the starter cranking the engine the voltmeter will read the voltage drop in the starter circuit - if the reading is not over ½ volt, it confirms that the circuit and connections are good.

Starters With Integral Switches.

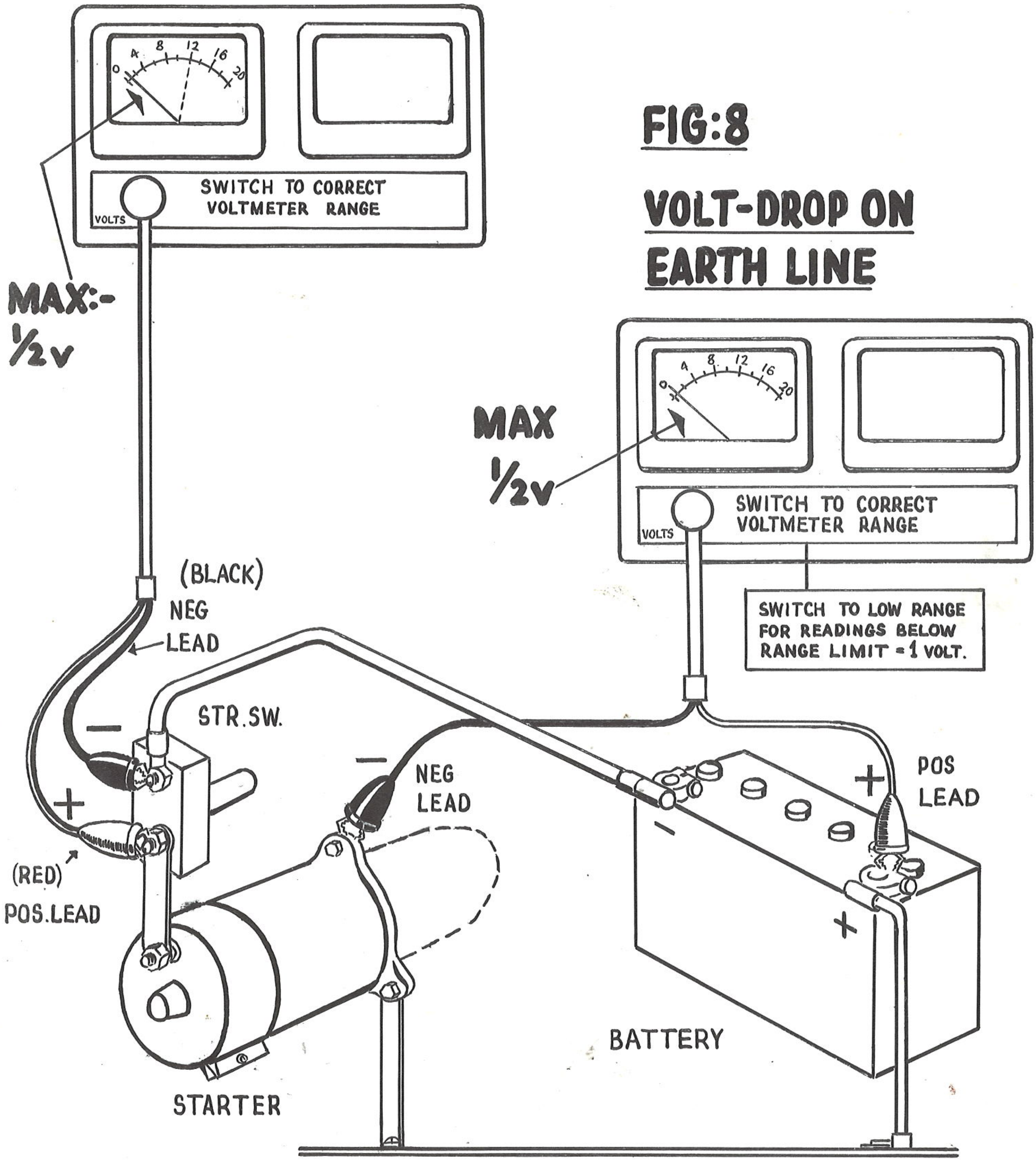
Where the starter switch is integral with the starter and only the "battery" terminal is accessible, the starter cover band should be removed and the voltmeter lead clip held in contact with the live starter brush as the starter is operated.

The voltage now shown will include the drop due to the resistance of the starter field coils and the minimum voltage at the starter should be 9·25 volts for 12-volt systems or 4·25 volts for 6-volt systems. The volt-drop reading in the second test should not exceed ¾ volt.

FIG: 7 VOLT-DROP ON STR. SWITCH

FIG: 8

VOLT-DROP ON EARTH LINE


0
4
8
12
16
20
SWITCH TO CORRECT VOLTMETER RANGE
VOLTS
MAX:-
½v
(BLACK)
NEG
LEAD
−
+
STR.SW.
(RED)
POS.LEAD
STARTER
MAX
½v
SWITCH TO LOW RANGE FOR READINGS BELOW RANGE LIMIT = 1 VOLT.
NEG
LEAD
POS
LEAD
BATTERY

TESTING STARTER SWITCH AND BATTERY AND STARTER EARTH CONNECTIONS.

In the previous test the voltage drop across the whole of the starter cable and switch section was measured. If the voltage drop is excessive, it is necessary to determine whether the main loss of voltage is in the switch or the cable section. The switch is a frequent cause of the trouble because this is the most heavily stressed unit in the starter circuit, being subject to repeated operation, which causes the switch contacts to become burned and resistive in normal usage.

TESTING STARTER SWITCH - (FIGURE 7)

The first test is to check the volt-drop across the starter switch and ascertain whether a deterioration of its contacts is sufficient to affect starter performance. The voltmeter is connected as shown in Figure 7. When the starter switch is open, the voltmeter will register the full battery voltage. If, on closing contacts with a separately mounted switch, the voltmeter reading does not exceed ½ volt, the switch contacts are in good electrical condition. If the voltmeter reading is higher than ½ volt, the switch contacts need cleaning or replacement.

In the case of a yoke mounted switch, the voltmeter connection will have to be made at the live brush as representing the starter side of the switch and in this case the voltmeter reading should be within ¾ volt in order to allow for the added resistance of the starter field windings.

TESTING EARTH CONNECTIONS - (FIGURE 8).

This test checks the battery and starter earth connections and is made with a voltmeter connected as shown in Figure 8. With the starter operating, the voltmeter reading should not exceed ½ volt. If the voltage reading is higher than ½ volt, it shows that there is excessive resistance in the connection of the starter body or engine block to the chassis, or of the connection from the battery earthed terminal to the frame.

If a relatively high voltmeter reading of over 1 volt is observed, this may be due to the engine bonding strap not being properly attached at both ends to clean metal. It is not unknown for this strap connection to be overlooked when the engine has been removed from the chassis for servicing.

FIG. 9. GENERATOR ARMATURE CHECK

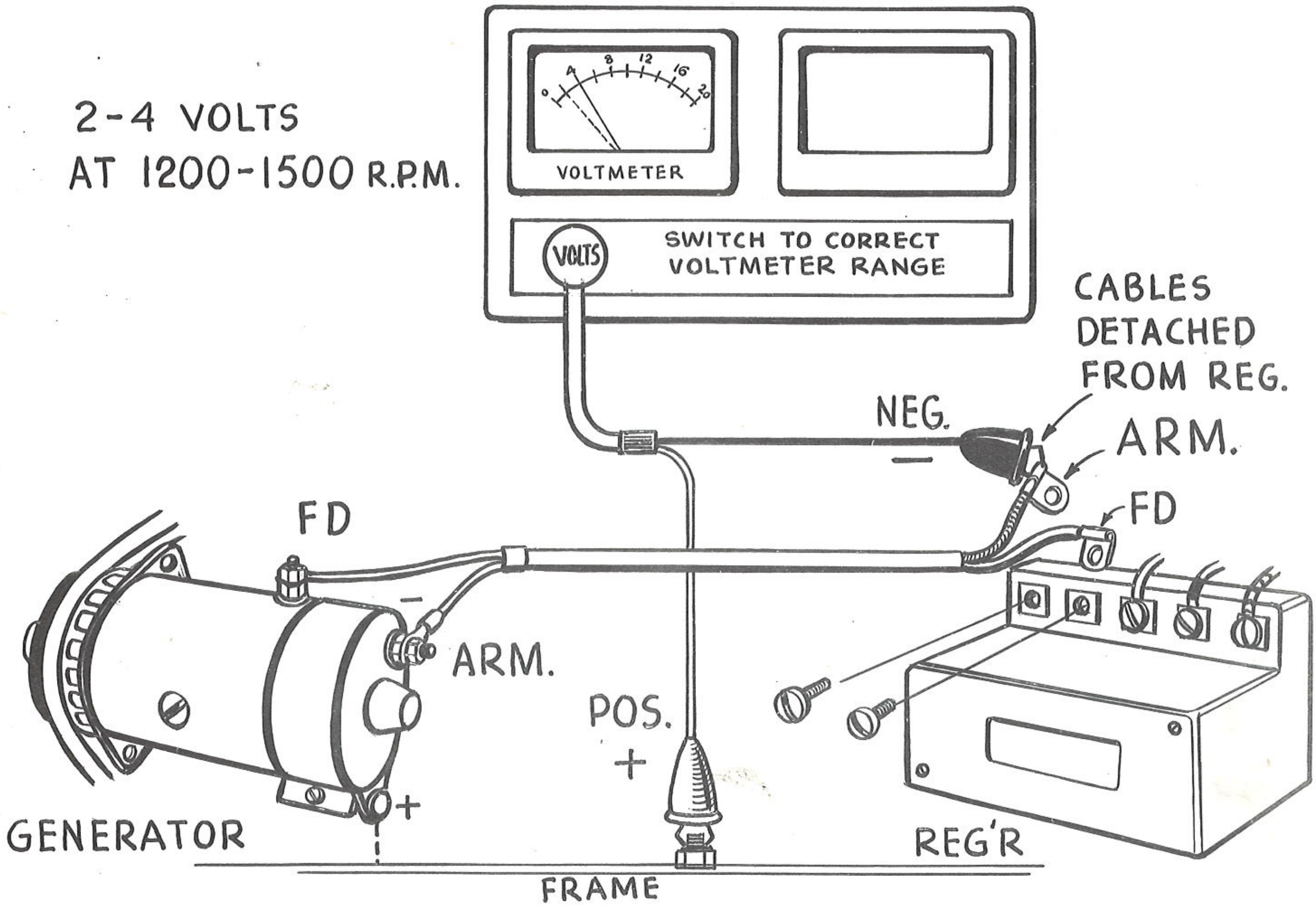
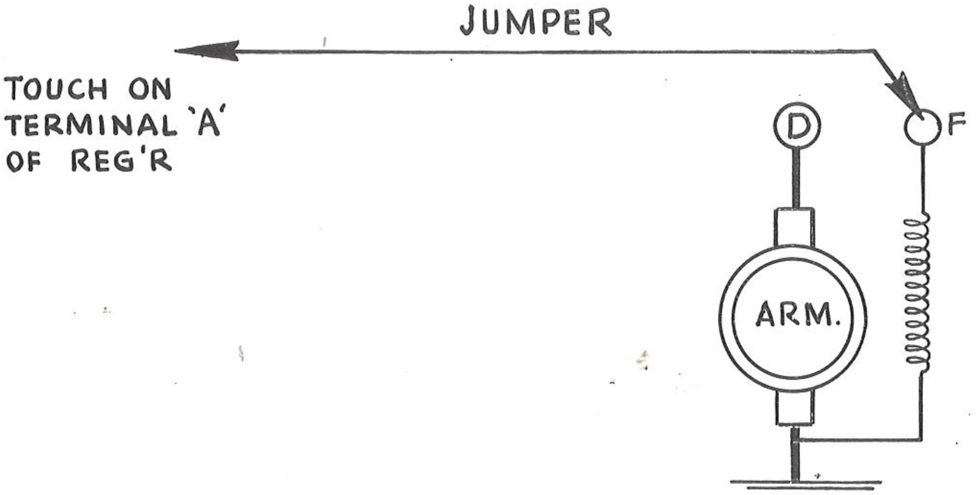

2-4 VOLTS
AT 1200-1500 R.P.M.
0
4
8
12
16
20
VOLTMETER
VOLTS
SWITCH TO CORRECT
VOLTMETER RANGE
CABLES
DETACHED
FROM REG.
NEG.
−
ARM.
FD
FD
−
ARM.
POS.
+
+
GENERATOR
REG'R
FRAME

FIG. 10 POLARISING 'B' FIELD


JUMPER
TOUCH ON
TERMINAL 'A'
OF REG'R
D
F
ARM.

GENERATOR TESTS

LUCAS GENERATORS

The method recommended for testing the condition and performance efficiency of Lucas generators is to make separate tests of the generator armature and field system. The armature test verifies the condition of the armature, commutator and brushes and the field system test verifies that the field current is within normal limits.

ARMATURE TEST - (FIGURE 9)

In making the test of the armature, both the armature and field circuit are isolated from the rest of the system and the test voltmeter is connected across the main terminal and earth, i.e., across the armature brushes.

To make the test, first remove the jumper lead previously connected between the distributor L.T. terminal and "Earth". Also remove the armature and field cables from the regulator as shown in Figure 9. With the voltmeter connected as shown, and with the engine running at 1500 R.P.M. the generator field system is disconnected and the voltage generated will be that due to the residual magnetism in the machine. The reading obtained will, therefore, be evidence of the condition of the armature, since the field system is temporarily disconnected.

The voltmeter readings obtained will vary with different generators, but will average between two and four volts. If the voltage reading is outside these limits, reconnect the cables at the regulator and remove the other ends of the cables at the generator. Then repeat the test which will verify if the trouble is in the cables.

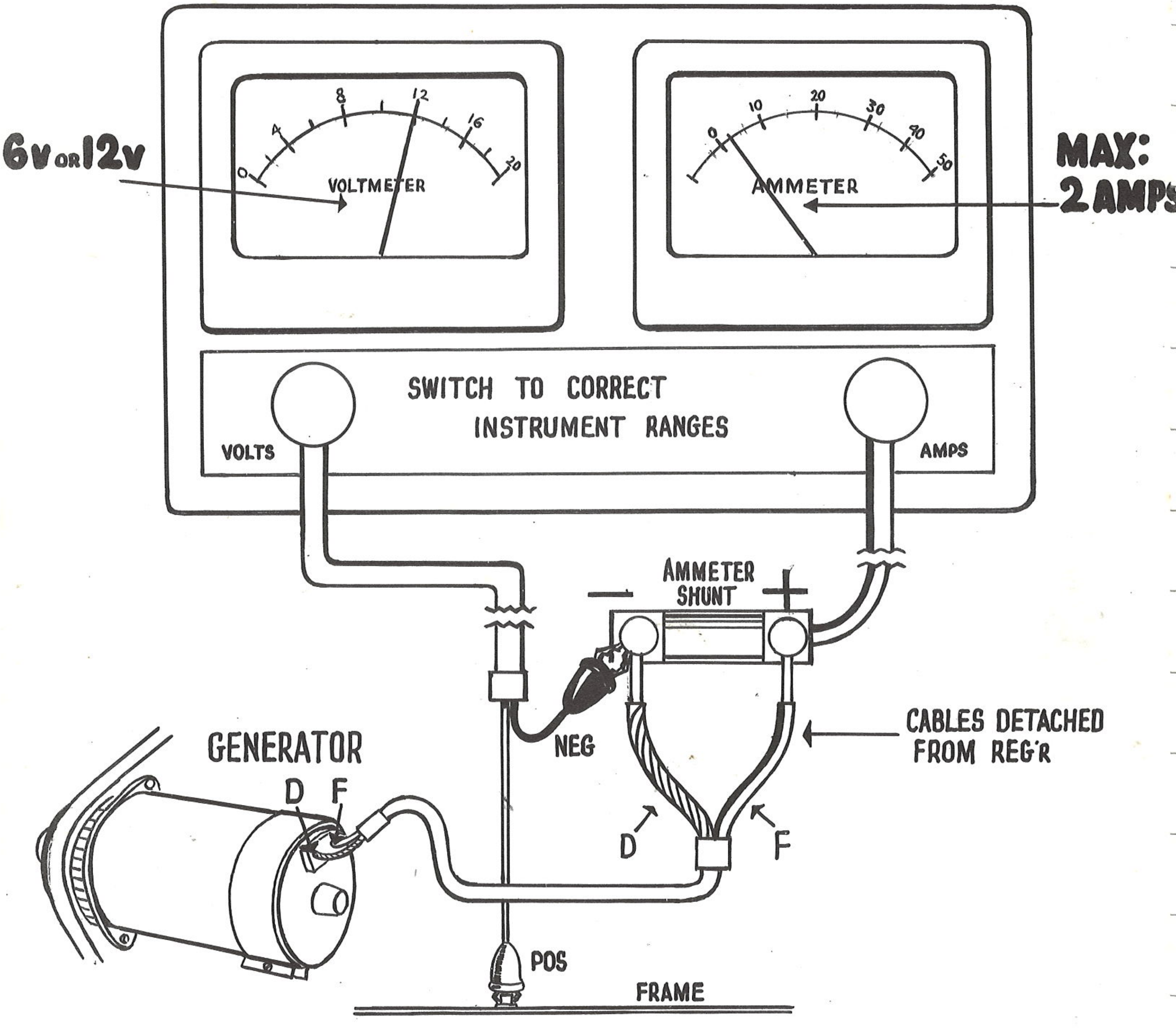
The test made gives a reliable indication of the general condition of the armature, commutator, brushes, connections, etc. Any internal defects such as a dirty commutator, poor brush contact, or sticking brushes, will introduce enough resistance to prevent the generator reading normal residual field voltage.

The test also shows if the residual magnetism of the generator has been accidentally reversed. This is shown where the voltmeter reads off scale - to the left of zero. Before accepting this reverse reading as evidence of reversed polarity, make sure that the test connections are correct for the type of generator being tested.

POLARISING THE GENERATOR - (FIGURE 10).

To correct reversed polarity, connect as shown in Figure 10. All cables are detached from the generator and a jumper lead is clipped to the generator "F" terminal and the other end of this lead momentarily touched on the "A" terminal of the regulator, or the live terminal of the battery. This causes a flow of battery current through the field coils which will magnetise the pole shoes in the correct polarity, causing the voltmeter to register in the proper direction when the open field generator armature test is repeated.

FIG:11 GENERATOR FIELD TEST


6V OR 12V
VOLTMETER
0
4
8
12
16
20
AMMETER
0
10
20
30
40
50
MAX:
2 AMPS
SWITCH TO CORRECT
INSTRUMENT RANGES
VOLTS
AMPS
AMMETER
SHUNT
−
+
CABLES DETACHED
FROM REG'R
GENERATOR
D
F
NEG
D
F
POS
FRAME

TESTING GENERATOR FIELD CURRENT - FIGURE 11.

The purpose of this test is to verify if the generator field current is normal. The test is made by connecting an Ammeter in the field circuit and measuring the current flow in the field windings at nominal running voltage.

When making this test, careful control of the generator speed is necessary because the field circuit is connected directly across the armature with no regulation or restriction imposed. Under this condition the current is approximately proportional to speed and will reach an excessive value if the speed is permitted to rise too high.

Figure 11 shows the test voltmeter and ammeter connected for carrying out the test. The voltmeter is connected across the armature and the ammeter connected in the field circuit. These connections apply to a generator with internally earthed fields as with British vehicles and also some types of U.S.A. built Ford vehicles, and heavy duty Delco-Remy and Auto-Lite equipment.

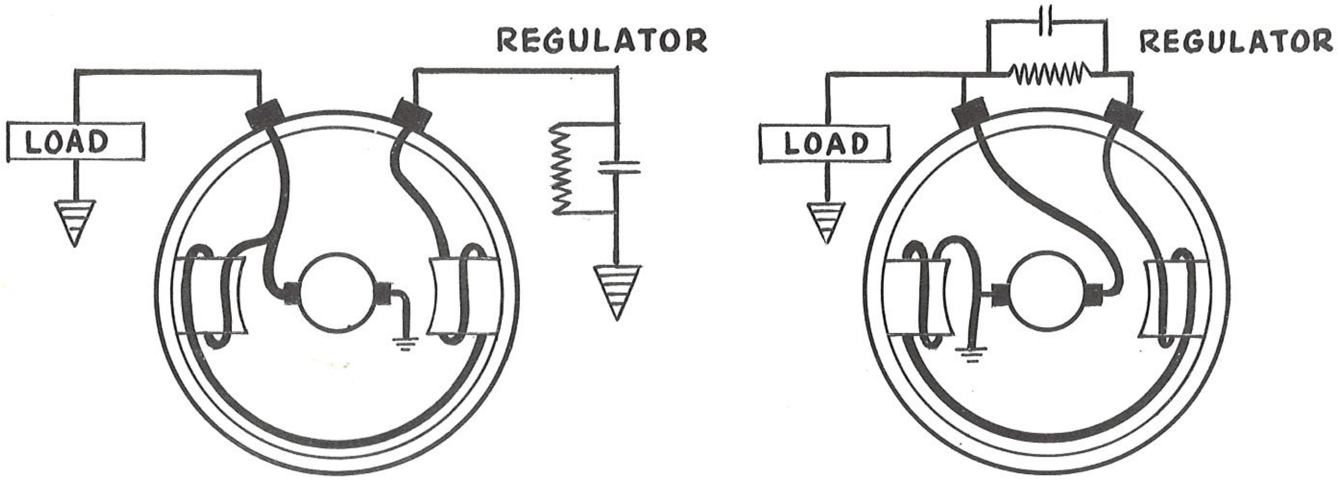
With the voltmeter and ammeter connected the generator speed should be gradually increased. This will cause the voltage to rise steadily and the engine speed should be held constant, when a voltmeter reading of 6 volts or 12 volts is reached. The field current at this voltage should be approximately 2 amperes.

A reliable check of the field condition can be made by referring to the manufacturer's service data, which gives the field coil resistance. By dividing the generator voltage by the value of this resistance, the result should agree with the ammeter reading of field current.

Any excess reading will indicate the possibility of inter-turn shorts in the field coils. A low field current reading will indicate excessive resistance in the coils or the internal connections. In either event, the generator is in need of service.

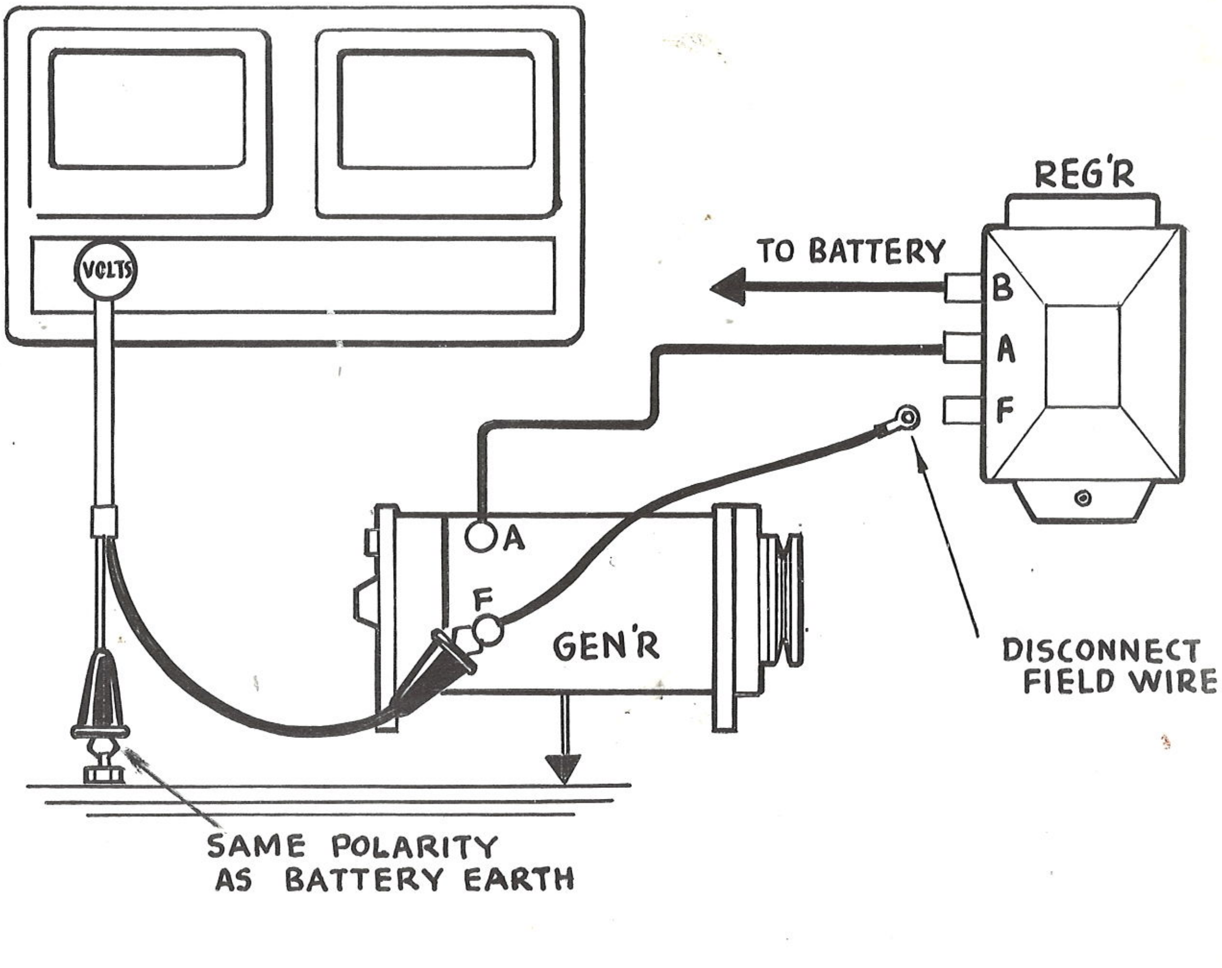
When making the test it is important that the field current readings are taken at the nominal voltage of the generator; care must be taken to avoid running the generator above the nominal voltage, as this will overload and heat the field coils.

FIG.12. USA. 2 BRUSH GENERATOR CIRCUITS


REGULATOR
LOAD
REGULATOR
LOAD

A STANDARD DUTY TYPE B HEAVY DUTY TYPE

FIG.13. IDENTIFICATION OF TYPES OF USA GENERATOR FIELD CIRCUITS.


VOLTS
REG'R
TO BATTERY
B
A
F
A
F
GEN'R
DISCONNECT FIELD WIRE
SAME POLARITY AS BATTERY EARTH

TESTING U.S.A. GENERATORS.

There are two types of field circuits used in Delco, Auto-Lite and Ford generators. Standard Delco-Remy and Auto-Lite generators have the field earthed (grounded) external to the generator and through the regulator contact points as shown in Figure 12A - these machines are called standard duty type. Heavy duty Delco-Remy and Auto-Lite generators and all Ford generators have the field internally earthed (grounded) as shown in Figure 12B. These different field connections do not affect the operation of the generator but they do affect the method of testing and polarising.

HOW TO IDENTIFY THE TYPE OF FIELD CIRCUIT.

A simple voltmeter test will identify whether the generator is of the standard duty type with an external earthed field or a heavy duty type with an internal earthed field. Disconnect the field wire at the "F" terminal of the regulator, taking care to see that the wire does not come into contact with earth (ground). Then connect a voltmeter from the generator field terminal and earth as shown in Figure 13. Start the engine and run at a fast idle speed. If the voltmeter shows a reading, the generator is of standard duty type with an external earth. If there is no voltage reading, the generator is of the heavy duty type with an internal earth.

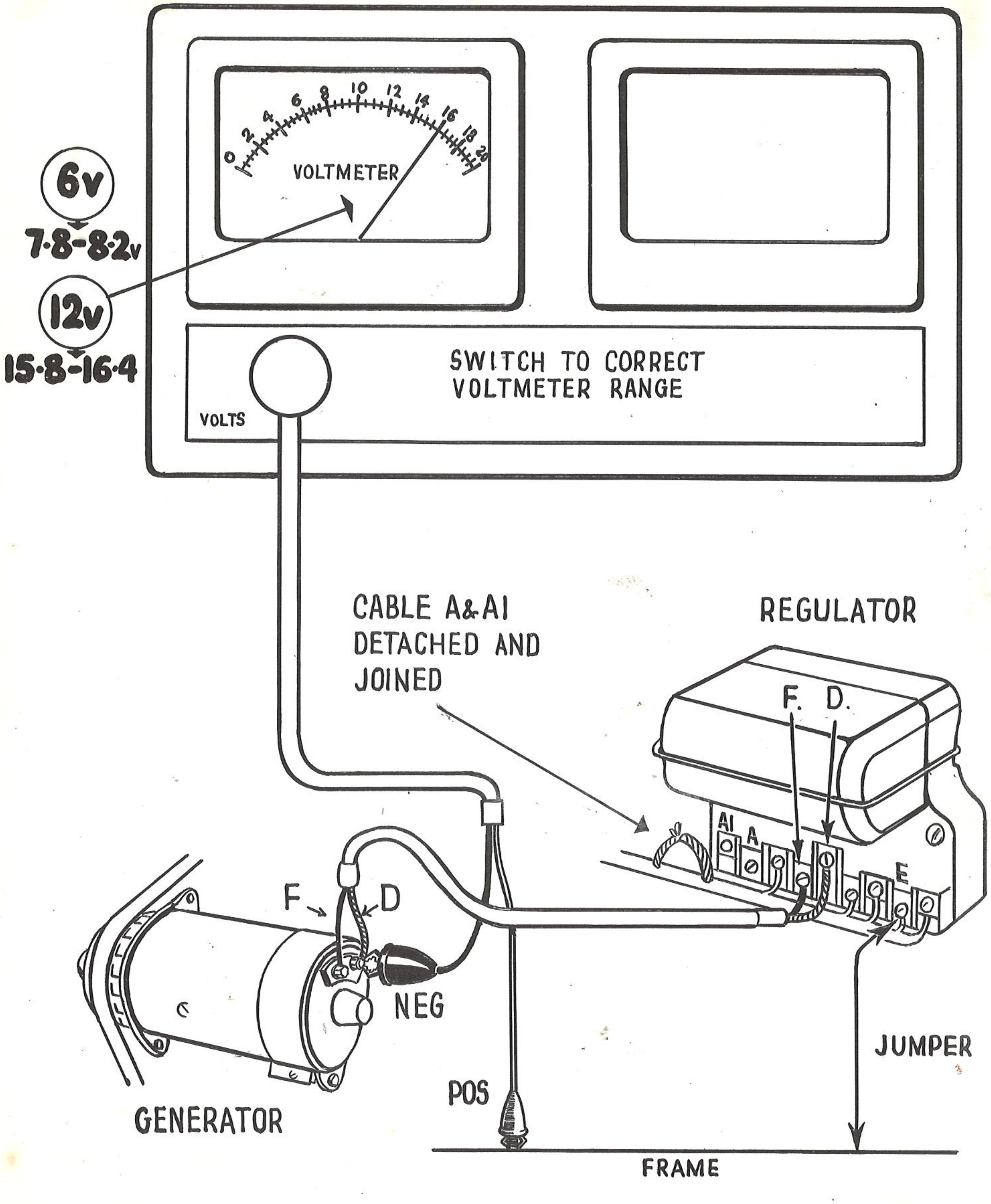
POLARISING.

Whenever a generator or regulator is checked, adjusted or replaced, a test should be made of the generator polarity. If incorrect, the generator must be re-polarised. This can be done by connecting a jumper lead before the engine is started. The method of connecting the lead varies according to the type of generator as follows:-

With standard duty generators - normal Delco-Remy or Auto-Lite - the earthed brush must be lifted or insulated from the commutator. A jumper lead is connected momentarily between the battery and generator terminals of the regulator, and the field terminal is connected to earth (ground).

On Ford generators and heavy duty Delco-Remy and Auto-Lite, the field lead is disconnected at the regulator field terminal and contact momentarily made to the battery terminal.

FIG:14 VOLTAGE REGULATOR TEST



SWITCH TO CORRECT VOLTMETER RANGE

CABLE A&A1 DETACHED AND JOINED

6v
7·8–8·2v
12v
15·8–16·4
0
2
4
6
8
10
12
14
16
18
20
VOLTMETER
VOLTS
REGULATOR
F. D.
A1
A
E
F
D
NEG
POS
GENERATOR
JUMPER
FRAME

REGULATOR SERVICE

The term "regulator" is usually used to define the control box which, in addition to the voltage regulator, (and in U.S.A. equipment also a current regulator) also includes the cut-out.

The regulator has deliberately been left late in the test procedure because, before testing the regulator, tests must be made of the battery, generator and the charging circuit.

Before making an electrical test, the control box unit should be visually inspected. Points to be checked include terminals and earth connections, condition of contacts, and resistors, condition of winding and signs of overheating and any obvious mechanical deficiencies. A check should also be made to verify that the regulator is of the correct type, voltage and polarity, in accordance with the manufacturer's specifications for the vehicle being tested.

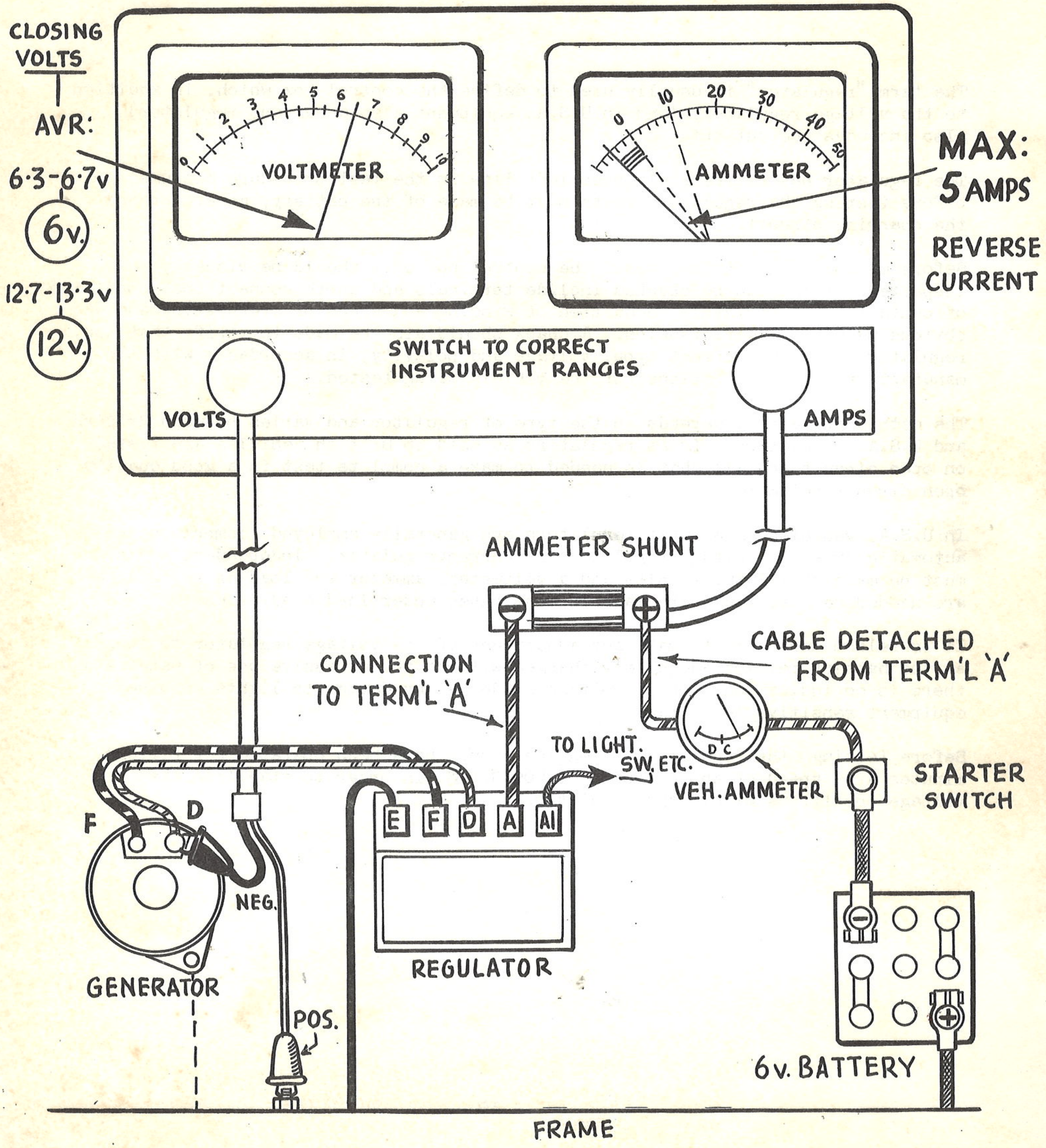
The method of testing depends on the type of regulator and varies between British and U.S.A. regulators. Lucas regulators as used on British vehicles are tested on open circuit and all that is needed to make a complete test is a good quality open circuit voltmeter.

In U.S.A. vehicles three-unit regulators are generally employed, comprising an automatic cut-out, voltage regulator and currentregulator, Independent tests must be made of all three units and a voltmeter, ammeter and loading resistance are needed because tests are made in most cases under load conditions.

It is seldom necessary to make any adjustment of the voltage regulator so long as the battery remains adequately charged without the excessive use of water and there is no indication of high voltage evidenced by damage to lights or other equipment sensitive to voltage.

Before testing the regulator the engine should have been operated for fifteen minutes at a speed of about 1,000 - 1,500 R.P.M. in order to stabilise the voltage conditions within the regulator.

FIG. 15. CUTOUT VOLTAGE & CURRENT TESTS


CLOSING VOLTS
AVR:
6·3-6·7v
6v.
12·7-13·3v
12v.
0 1 2 3 4 5 6 7 8 9 10
VOLTMETER
0 10 20 30 40 50
AMMETER
MAX: 5 AMPS
REVERSE CURRENT
SWITCH TO CORRECT INSTRUMENT RANGES
VOLTS
AMPS
AMMETER SHUNT
CABLE DETACHED FROM TERM'L 'A'
CONNECTION TO TERM'L 'A'
TO LIGHT. SW. ETC.
D C
VEH. AMMETER
STARTER SWITCH
F
D
NEG.
E
F
D
A
A1
REGULATOR
GENERATOR
POS.
6v. BATTERY
FRAME

TESTING LUCAS REGULATORS.

In earlier tests we have checked the battery, starter operation and the generator for armature condition and field current. The generator is now connected through its regulator and a test is made to establish the level at which the generator voltage is held constant. Tests are made with the generator on open circuit with the battery disconnected.

Figure 14 shows the voltmeter connections, these being for positive earth return systems.

As an alternative to the connections shown in Figure 14, the voltmeter can be attached to the "D" terminal of the regulator or the regulator frame. When using this point of connection it is essential to see that the test lead clip does not impede the movement of the armature plate of either the cut-out or voltage regulator.

To establish an open circuit it is necessary to open the battery line. This can be done by either of the following methods.

(1) Insert a slip of dry paper or other insulation between the cutout contacts.

(2) Disconnect both the "A" and "A1" cables from their terminals and join the cables together. Figure 14 illustrates this method.

With the voltmeter correctly connected, start the engine and increase the speed gradually, watching the gradual rise in the voltmeter reading. The voltmeter pointer will be seen to settle at a steady reading which does not increase with any further rise of speed. This is the regulated voltage and the engine speed should not be increased beyond this point. ON NO ACCOUNT RACE THE ENGINE DURING THE TEST.

Check the voltage setting with the manufacturer's data for the type of regulator concerned. As a general guide, the following figures apply:-

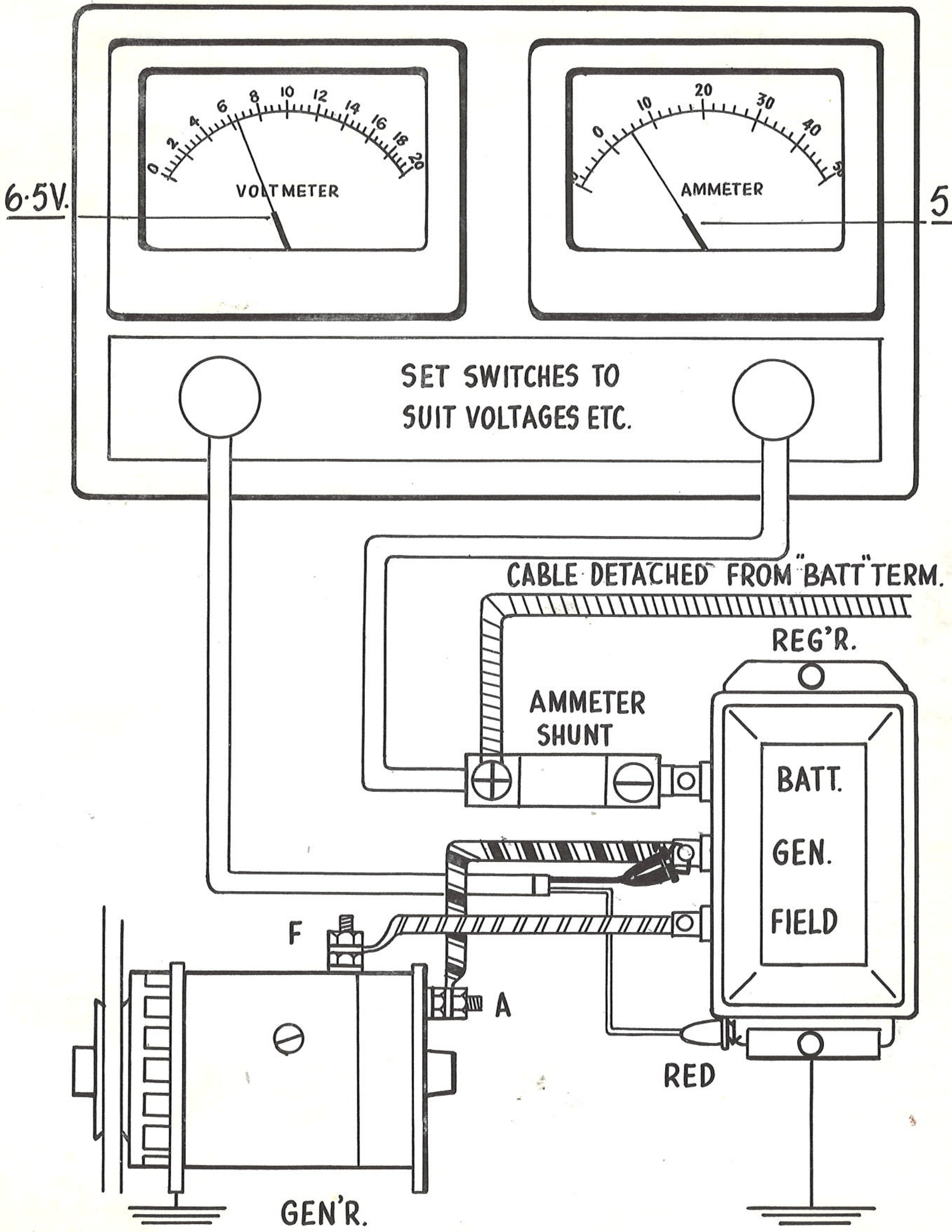
At a temperature of 60° - 70° F. checked with a thermometer held against the regulator bobbin.

6 volt equipment	...	...	7·8 - 8·2 volts.
12 volt equipment	...	...	15·8 - 16·4 volts.

After checking the voltage regulator setting, connect a jumper lead between the regulator "E" terminal and "earth" as shown in Figure 14 and repeat the voltage setting test. Any noticeable decrease in voltage indicates that there is excessive resistance in the earth line. Check the connections at both ends and also examine the condition of the cable.

On completing the test, slow down to idling speed, remove the jumper lead, remove the insulation slip from the cut-out or reconnect the "A" and "A1" cables to the correct terminals.

FIG:16 TESTING CUTOUT RELAY



0
2
4
6
8
10
12
14
16
18
20
VOLTMETER
6·5V.
0
10
20
30
40
50
AMMETER
5A.
SET SWITCHES TO
SUIT VOLTAGES ETC.
CABLE DETACHED FROM "BATT" TERM.
REG'R.
AMMETER
SHUNT
BATT.
GEN.
FIELD
F
A
RED
GEN'R.

CUT-OUT TESTING - LUCAS REGULATORS.

This is an allied test to the check of the voltage regulator setting and its purpose is to verify the operation of the cut-out. To do this, a test is made at the voltage at which the cut-out points close and also the drop-off voltage and the reverse current at which the contacts separate.

Figure 15 shows the test connections, the test voltmeter being again connected across the generator armature, either at the generator or at the "D" terminal of the regulator.

A test ammeter is connected in series with the battery cable line or may be connected in series with the generator cable to the regulator. When this latter connection is used, the field current is also registered and allowance should be made for this by deducting the two amperes average field current when determining the cut-out reverse current.

CHECKING CUT-OUT CLOSING VOLTAGE.

To check the closing voltage of the cut-out, the engine speed is gradually increased and the voltmeter reading carefully noted. The reading will be seen to drop slightly to a lower steady value when the cut-out contacts close. The cut-in or closing voltage is the maximum voltage shown before the reading drops, and should comply with the manufacturer's specified setting. The average closing voltage is -

6 volt cut-outs	...	6·3 - 6·7 volts.
12 volt cut-outs	...	12·7 - 13·3 volts.

TESTING REVERSE CURRENT.

To test the cut-out reverse current the engine speed should be increased to show a charging current of 5 to 10 amperes and then gradually decreased, carefully observing the ammeter. The current will be seen to decline to zero and then reverse to the left of the zero mark on the ammeter dial, until the contacts open and the pointer returns to zero. The reverse current setting of the cut-out is the maximum reverse current shown before the contacts open and must comply with the manufacturer's data. As a general guide, the reverse current should not exceed 5 amperes. As previously mentioned, where the ammeter is connected in the generator cable line, allowance must be made for the 2 amperes average field current.

CUT-OUT OPENING VOLTAGE.

Where the manufacturer's service data states the cut-out opening point in terms of opening or "drop-off" voltage, this is the minimum level to which the generator falls before the cut-out opens. The voltmeter when connected as shown in Figure 15 will show this opening voltage.

TESTING U.S.A. REGULATORS.

Most U.S.A. regulators are of the three-unit type, containing a cut-out relay, voltage regulator and current regulator. These units are mounted on a single base and comprise a single control box, but each has its own function to perform.

The cut-out relay is a magnetic switch which opens and closes the circuit between the generator and the battery as explained. When the generator is operating at charging speed the cut-out relay connects the generator to the battery and charging current flows. When the generator slows down below the charging speed, the cut-out relay opens the circuit between the generator and the battery.

Regulators in U.S.A. systems are not so simple as in the case of Lucas equipped British vehicles. Regulators are used with third-brush, and two-brush regulators and may consist of a voltage regulator, current regulator or combined current-voltage regulator. In all cases, however, the basic principle of regulation remains unaltered, and is the regulation of the generator by varying the strength of the magnetic field. No matter what the type of regulator, its basic function is to insert a resistance in series with the field current at the right time in order to maintain pre-determined generator output conditions.

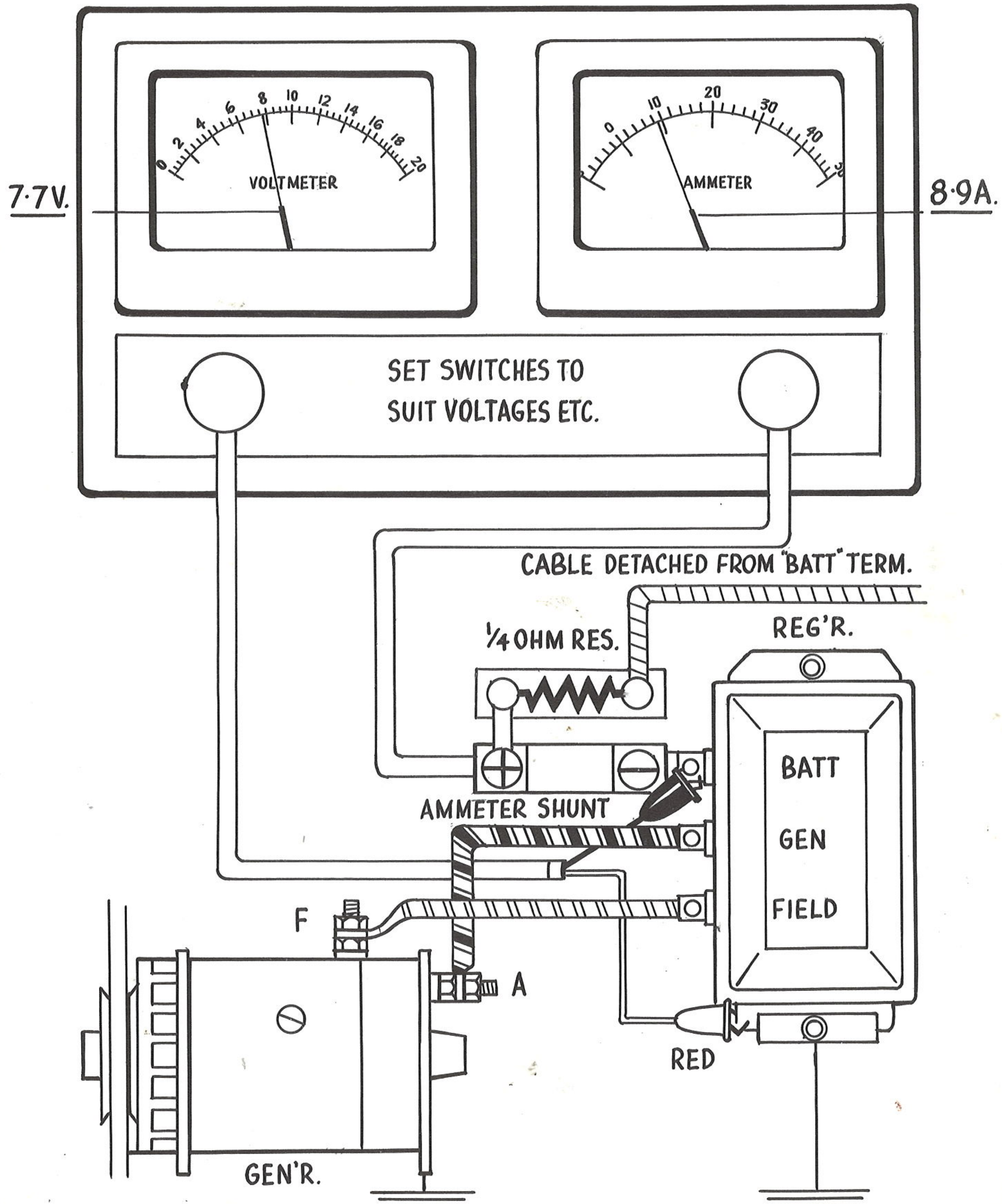
The basic function of the voltage regulator is to limit the generator maximum voltage and prevent it from going above this voltage in order to protect the battery from overcharging and the electrical system from high voltage.

The basic function of the current regulator fitted to U.S.A. vehicles is to limit the current from rising above a pre-determined value in order to protect the generator from overloading and consequent damage.

Before carrying out any tests of the regulator, previous tests must be made to the battery, generator and charging circuit. Tests can then be made of the regulator and should include a careful visual inspection, followed by a check of voltage and current settings.

Many U.S.A. regulators are designed with temperature compensation and must be tested when hot. Most regulator covers are made of steel which is a magnetic material and it is essential that the steel cover is in place when the tests are made. Where covers are of aluminium or plastic it is not essential that they are in place from a magnetic point of view, but their removal will affect the temperature conditions in the regulator.

FIG:17 TESTING VOLTAGE REGULATOR


0
2
4
6
8
10
12
14
16
18
20
VOLTMETER
7·7V.
0
10
20
30
40
50
AMMETER
8·9A.
SET SWITCHES TO
SUIT VOLTAGES ETC.
CABLE DETACHED FROM "BATT" TERM.
¼ OHM RES.
REG'R.
BATT
GEN
FIELD
AMMETER SHUNT
F
A
RED
GEN'R.

SPECIAL INFORMATION ON U.S.A. REGULATOR TESTING

The regulator, by its action in maintaining the charging circuit voltage, protects the battery from excessive charging rates, the distributor points, lamps and other accessories from high voltage and also the generator from possible damage due to overloading. .

It is essential that the cutout relay, voltage regulator and current regulator work within the manufacturer's specified limits. Under normal conditions the setting should be half way between the maximum and minimum limits given in the maker's data. If this setting of the voltage regulator results in a need for excessive topping up of the battery, the regulator setting should be lowered towards the minimum; if the battery tends to discharge quickly, the regulator setting should be towards the maximum.

All voltage regulator settings are given at stipulated temperatures and a test of the ambient temperature must be carried out.

The voltage regulator cover is part of the magnetic circuit of the regulator and must be in place when tests are made.

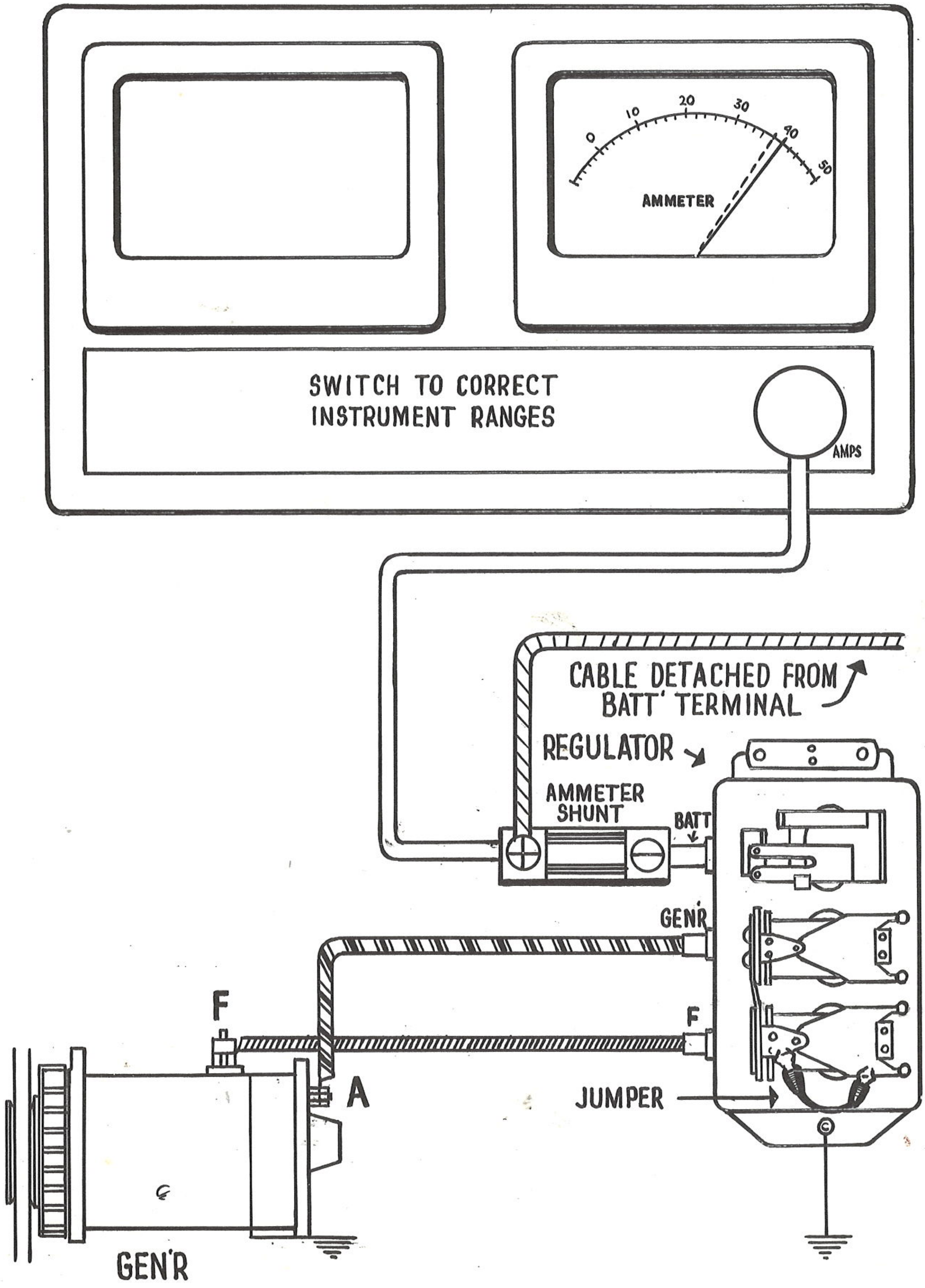
When testing regulators removed from the engine, it is essential that they are operated with the same type of generator for which they are designed.

Irregular regulator action is frequently due to the contact points becoming dirty or oxidised. All contacts which carry electric current need cleaning at regular intervals.

When testing or adjusting the regulator, the cut-out points must never be closed by hand with the battery connected to the regulator. If this is done a high current will flow through the unit which will cause serious damage.

If the cut-out, voltage regulator or current regulator do not test within the manufacturer's specified limits or do not hold their settings, the regulator must be removed for servicing or replacement.

FIG:18 TESTING CURRENT REGULATOR


0
10
20
30
40
50
AMMETER
SWITCH TO CORRECT
INSTRUMENT RANGES
AMPS
CABLE DETACHED FROM
BATT' TERMINAL
REGULATOR
AMMETER
SHUNT
BATT
GEN'R
F
F
A
JUMPER
GEN'R

TESTING U.S.A. REGULATORS.

STABILISING PERIOD.

Before making any tests of the regulator, the engine should be run for fifteen minutes at a speed of 1500 R.P.M. to stabilise voltage conditions in the regulator. This should be done irrespective of the prior operation of the vehicle.

CUT-OUT RELAY TEST.

The connections for making this test are shown in Figure 16, a voltmeter being connected at the regulator "GEN" or "A" terminal and the regulator frame and an ammeter connected into the charging circuit at the "BAT" or "B" terminal of the regulator.

Gradually increase the speed of the engine and note the voltage reading just before the cut-out points close. This reading should comply with the manufacturer's official settings.

The cut-out reverse current is tested by increasing the engine speed until a charging rate of approximately 20 amperes is obtained, and then by reducing the engine speed, noting the reverse current required to open the contacts. This reading of reverse current will be shown on the left side of the ammeter zero.

TESTING VOLTAGE REGULATOR.

The connections for testing the voltage regulator are shown in Figure 17, and since U.S.A. regulators are tested on load, it is necessary to connect a resistor into the charging circuit. This should have a value of ¼ ohm and not less than 25 watts and is connected into the charging circuit at the "BAT" or "B" terminal of the regulator.

A voltmeter is connected from the regulator "BAT" or "B" terminal to "Earth". All load other than ignition must be switched off. With the engine running at approximately 2,000 R.P.M. the voltmeter will indicate the voltage regulator setting which must comply with manufacturer's specifications.

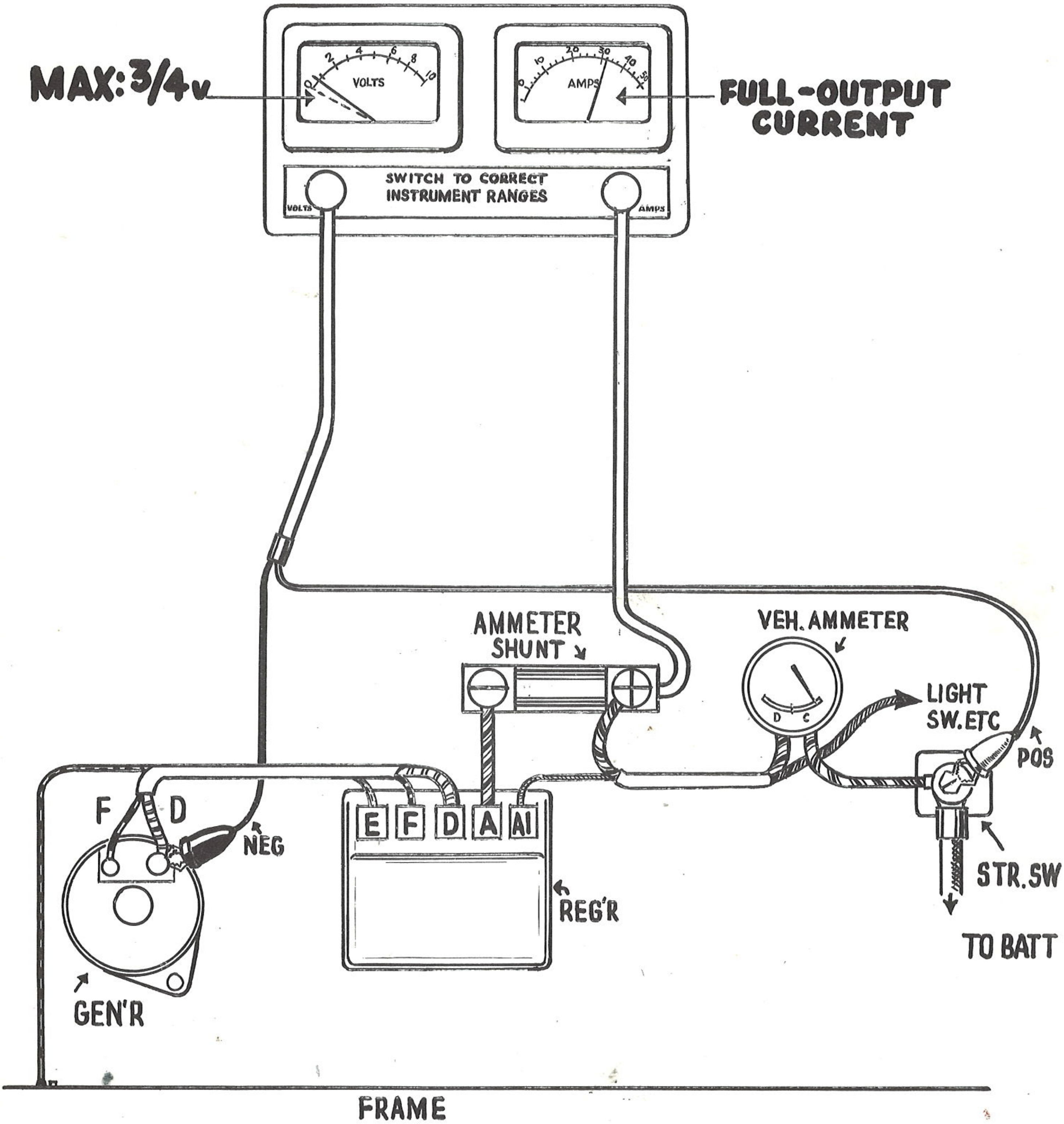
CURRENT REGULATOR TEST.

Connections for testing the current regulator are shown in Figure 18, an ammeter being connected in circuit between the "BAT" or "B" terminal of the regulator.

All lights and accessories must be switched on and a jumper lead connected across the voltage regulator points. Alternatively, a load can be placed across the battery, approximately equal to the current regulator setting.

To carry out the test, increase the engine speed and note the maximum reading on the ammeter which should comply with manufacturer's specifications.

FIG:19 CIRCUIT VOLT-DROP TEST


MAX: 3/4 v
VOLTS
0
2
4
6
8
10
AMPS
0
10
20
30
40
50
FULL-OUTPUT CURRENT
SWITCH TO CORRECT INSTRUMENT RANGES
VOLTS
AMPS
AMMETER SHUNT
VEH. AMMETER
D
C
LIGHT SW. ETC
POS
STR. SW
TO BATT
F
D
NEG
E
F
D
A
A1
REG'R
GEN'R
FRAME

TESTING CHARGING CIRCUIT VOLTAGE DROP.

The final stage of a systematic electrical diagnosis is a test of the voltage drop conditions in the entire charging circuit, in order to disclose any undue resistance or loss of conductivity.

The connections for making the test are shown in Figure 19, but before the voltmeter leads are connected, the generator must be running and current flowing in the charging circuit.

Run the generator at full output and with the voltmeter negative lead clipped to the generator terminal, touch the positive voltmeter lead clip to the live terminal of the battery or starter switch. The maximum voltmeter reading should not exceed $\frac{3}{4}$ volt. A reading in excess of this voltage indicates undue resistance in the cut-out contacts, series coils, main connections, panel ammeter, wiring, etc.

When making the test, the voltmeter positive test lead must be disconnected before the generator speed is reduced and the cut-out opens. If it is left connected with the generator running below the charging speed, the voltmeter will show a reverse reading.

If, when making the test, the battery is substantially charged, the lights and accessories should be switched on to increase the load and the charging rate, and thus reproduce the full voltage drop in the system to enable it to be adequately measured.

Where the voltage drop exceeds $\frac{3}{4}$ volt, it is necessary to carry out tests to localise the section of the system in which trouble exists. This is achieved by connecting the voltmeter across various sections of the circuit in turn, the section producing the highest voltage drop indicates the area in which the fault exists.

COMPLETING THE DIAGNOSIS.

After completing the tests, make a careful check of the operation of electrical accessories and lights and all other factors which will contribute to a satisfied customer.

Remove all the test leads and make sure that all terminal connections are properly remade, check all the adaptors used and put these and the test instruments carefully away. Take special care not to leave any cables off or the bonnet open, in anticipation that the owner will automatically requisition the service work to be carried out immediately. It is better to leave the car so that the owner can drive it away if he wishes to do so, with the idea of bringing the vehicle back later on, for the work to be done.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 13

MODERN BATTERY SERVICING

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

MODERN BATTERY SERVICING

Battery service is a big and important business and offers excellent opportunities to enterprising service shops.

In 1958 there were nearly 8,000,000 motor vehicles on British roads and surveys predict over 12,000,000 within the next few years. The average life of an automobile battery is little more than two years. This means that nearly 4,000,000 motor vehicles will require battery replacement every year and many more will need battery servicing such as topping up, cleaning, recharging, and new connectors and cables. The number of people already engaged in the manufacture, servicing and sale of batteries is evidence of the importance and size of the battery business.

The battery is at one and the same time the most important, yet the most neglected component in the vehicle. Upon its satisfactory performance depends the starting performance and dependability of the engine. The fact that an increasing number of cars no longer have an alternative in the form of a starting handle makes the satisfactory condition of the battery even more important. Good battery condition is essential for the satisfactory operation of the electrical system, adequate lighting when the vehicle is stationary, and the general performance and road worthiness of the vehicle. Despite its importance, however, the battery is neglected by most owners and is not given the attention it deserves in regular inspection, testing and servicing by most service stations.

Where a planned programme of battery servicing has been developed, the results have been highly satisfactory. Owners respond to proved service needs such as recharging and replacement. The use and application of modern methods of battery testing and charging enable excellent profits to be earned.

HOW THE BATTERY WORKS

Basically, the automobile battery consists of a moulded box filled with two sets of lead plates, one containing red peroxide of lead and the other grey spongy lead. the plates being immersed in a solution of acid and water called the electrolyte. When an electrical load is connected to the battery the acid in the electrolyte combines with the lead in the plates and creates electricity.

When current is taken from the battery the acid begins to leave the electrolyte and enters the battery plates. This causes the plates to become coated with a combination of sulphuric acid and lead called sulphate. As the battery discharge continues, more acid leaves the electrolyte and combines with the lead plates and more sulphate is formed. Gradually both sets of plates change until they are lead sulphate and chemically similar; at this point the battery is considered to be discharged.

When the battery is charged by sending a current through it, the reverse process takes place. The passage of electricity through the battery re-converts the lead sulphate on the plates back into lead and acid leaves the plates and re-enters the electrolyte.

When acid leaves the electrolyte during discharge the specific gravity falls and when acid leaves the plates and re-enters the electrolyte during charging, the specific gravity increases. By measuring the specific gravity with a good Hydrometer the state-of-charge can be measured. The specific gravity is highest when the battery is fully charged and all the acid is in the electrolyte. The gravity is lowest when the battery is discharged and most of the acid has left the electrolyte to combine with the plates to form lead sulphate.

BATTERY TROUBLES

A number of things can go wrong with a battery. They include -

(1) The battery may become discharged through too much use or too little charging.

(2) A battery may be overcharged by allowing charging current to flow for too long a period. This will result in buckled plates and possible puncturing of separators.

(3) The battery may be low in electrolyte, causing the tops of the plates to become exposed, resulting in loss of effective plate area and a reduction in battery capacity.

(4) The battery may be loose and the resulting vibration may shake active material off the plates, lowering the capacity of the battery.

(5) The top of the battery may become covered with acid moisture and dirt which will result in self-discharge.

(6) The battery may lose electrolyte through a cracked case or leak.

(7) The battery will eventually become worn out as a result of constant charging and discharging.

SULPHATION

The major problem experienced in the servicing of batteries is sulphation. This is a word which all mechanics will have heard but do not properly understand.

The Cause of Sulphation.

When a battery is allowed to remain in a state of partial or full discharge for any length of time, the lead sulphate which normally forms on the plates becomes hard. This makes it difficult for further acid to penetrate into the plates and reduces the capacity of the battery for useful work. The longer the battery remains in a discharged condition, the harder the sulphate becomes. At first it is relatively soft; in time it becomes progressively harder and ultimately becomes crystalline and very brittle. In extreme cases the sulphate will expand and cause the plates to become warped or buckled. This pinches the separators and may ultimately result in the plates touching each other, causing the cell to become short circuited and ruining the battery. Sometimes this trouble is noticeable only in a single cell, but if the other cells are examined, it will be seen that the same kind of trouble is developing in these cells. To repair a single cell is not good practice and the entire battery should always be replaced or rebuilt.

Sulphation is a serious battery problem because it reduces the area of the plates by making it impossible for the acid in the electrolyte to act upon the active material of the plates and cause the chemical change which is responsible for the electrical performance of the battery. A battery which is normally large enough to do its job properly may, because of sulphation, have its size reduced by 50 per cent. or more and be totally incapable of giving satisfactory starting and ignition and lighting service.

CHARGING SULPHATED BATTERIES.

When a sulphated battery is discharged and is put on charge, it acts as though it is in a fully charged condition and, after a swing-over of the ammeter on the charge side, the reading will return shortly to nearly zero, and it will generally be concluded that the battery is fully charged. This makes it difficult for the owner to know when his battery is sulphated; its action makes him believe that it is fully charged and he is not aware of anything wrong until starting troubles develop.

The effect of sulphation is to increase the resistance of the battery and this is why the charging current is low when a normal charging voltage is applied. A higher voltage than normal is required to charge the battery. This is the reason why sulphated batteries are so troublesome and why they upset the normal operation of the vehicle electrical system.

When a normal battery becomes discharged it accepts the full output of the vehicle generator at the normal regulated voltage. As it becomes charged, its voltage rises and this causes the charging rate to reduce until, when the battery is fully charged, it will accept only a relatively small charging current.

A sulphated battery has a higher resistance and less active available plate area. The small amount of plate area soon becomes charged and the battery voltage rises rapidly, reducing the flow of current from the generator. The section of the battery plates which are heavily sulphated are not effectively charged because of the high resistance of the lead sulphate on the plate surface. In order to break down this lead sulphate it is necessary to supply a higher charging voltage than normal.

This cannot be done on the vehicle because an increase in the system voltage will result in a higher voltage being applied to the ignition system, lights, accessories, and car radio. The only solution is to remove the battery and charge it at a low charging rate for a long period in order gradually to break down the lead sulphate and restore normal battery condition.

STORING BATTERIES

Battery sulphation starts as soon as the specific gravity of the battery electrolyte falls below 1.250. This makes it important to see that batteries in storage are maintained at a higher specific gravity than 1.250. In many cases they are not and will become sulphated. The longer they are left the worse the sulphation becomes. This is the reason why new batteries, when fitted in cars, often give trouble. They have been kept in storage in a semi-charged condition and, as a result, have been allowed to become sulphated.

The same difficulty may be experienced with batteries on vehicles in stock. If the vehicle has been standing for any length of time, the battery can easily become sulphated. The average fall in specific gravity will be about 2 points of specific gravity per day at normal room temperature. If the temperature is high, the loss of specific gravity will be as much as 3 points per day. Because of this, batteries should never be stored in showroom windows subject to hot sun.

The loss of specific gravity when batteries are stored in a cool place is appreciably reduced. A battery stored at 80 degrees F. will lose about half its charge in 30 days, at 60 degrees F. the loss will be only about one quarter of the charge.

TESTING BATTERIES

One of the most important requirements in battery servicing is an effective method of testing. Two basic tests are needed:-

(1) A test of the state-of-charge of the battery.

(2) A test of battery capacity.

Both these tests are necessary in order fully to determine battery condition. A battery cannot be condemned as defective and in need of service or replacement by either test carried out alone.

The first test to make of any battery is to check its state-of-charge. This can be done by measuring the specific gravity with a Hydrometer, when the reading of each cell should be 1.250 or more and uniform within 25 points.

An easier and quicker test, however, can be made by measuring the open circuit voltage of the battery with a specially designed expanded-scale voltmeter. This is a specialised type of instrument which measures the voltage of the battery within limits of 1/100th volt. Each 1/100th volt reading of battery voltage is approximately equal to ten points of specific gravity.

The process of measuring battery open circuit voltage is by connecting the test prods of the instrument across each cell in turn, and noting the reading on a zoned scale as illustrated in Figure 1. Where all readings are in the "SERVICEABLE" zone and are uniform within 6 points, the battery has adequate charge for continued good service. This does not mean, however, that it is necessarily suitable for extended service because, although it may be fully charged, its capacity may be low. An additional test should, therefore, be made of the battery capacity by measuring the voltage of the battery while a current equivalent to the starting load is taken from it.

Batteries which read in the "RECHARGE" zone are less than half charged and can only be tested by passing current through the battery. This can be done by using a modern Fast Charger.

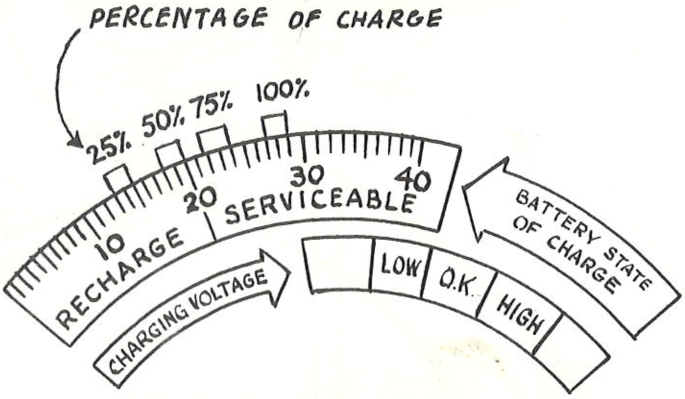
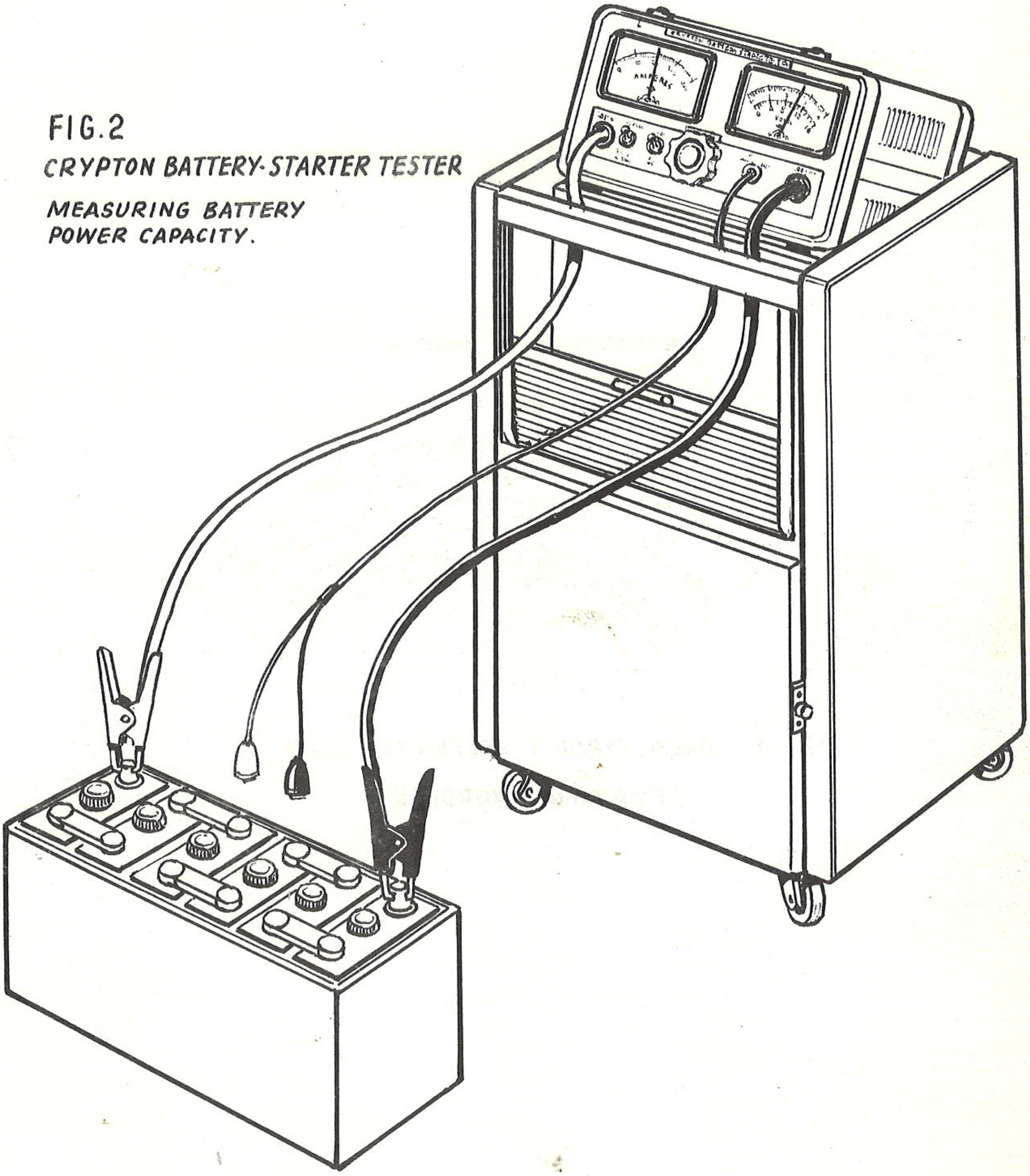

PERCENTAGE OF CHARGE
25%
50%
75%
100%
10
20
30
40
RECHARGE
SERVICEABLE
BATTERY STATE OF CHARGE
CHARGING VOLTAGE
LOW
O.K.
HIGH

FIG: 1 OPEN-CIRCUIT VOLTMETER SCALE
CRYPTON "HYDROLEK"

FIG.2

CRYPTON BATTERY-STARTER TESTER

MEASURING BATTERY
POWER CAPACITY.


AMPERES
VOLTS

To recapitulate - if the battery has enough charge in it as shown by the open circuit voltage test, the capacity of the battery can be tested by applying a load to it. If, however, the battery does not have enough charge in it, the capacity can be tested only by passing current through it.

OUTPUT TEST OF BATTERY CAPACITY

Where the state-of-charge test shows that the battery is sufficiently charged, a test of battery capacity is most accurately made by using a modern battery - starter tester as shown in Figure 2. This comprises a moving coil ammeter and voltmeter and a variable carbon pile resistance. The resistance enables the correct load to be applied to the battery. The ammeter measures this load. The voltmeter measures the voltage of the battery or the individual battery cells whilst the load is applied.

The test is made by connecting the ammeter and voltmeter leads of the tester to the battery posts in the correct polarity. The resistance control knob is adjusted until the ammeter reads three times the ampere hour rating of the battery. Thus, if the battery capacity is 50 ampere hours, the load control would be adjusted until the ammeter reads 150 amperes. The load is applied for 15 seconds, at the end of which a 6 volt battery should give a reading of not less than 4.8 volts and a 12 volt battery not less than 9.6 volts. All cell voltage readings should be uniform within 0.2 volts.

If the battery voltage is less than 4.8 or 9.6 volts, it does not necessarily mean that the battery is defective. The trouble may be sulphation or discharge. A final decision cannot be made until a further test is made by putting the battery on charge and testing it whilst charging current is flowing. This will show definitely whether the battery is good or no good.

MAKING A CHARGE-TEST OF A BATTERY

The purpose of a charge-test is to determine whether battery low capacity is due to a low state of charge, sulphation or the battery being worn out and in need of replacement. The test must only be made where batteries fail to pass the capacity test - it cannot be satisfactorily made on batteries which read 4.8 or 9.6 volts or higher on the capacity test.

To make a charge-test, the battery starter tester is removed and the battery connected to a Fast Charger and charged at a rate of 75 amperes for 6 volt batteries or 40 amperes for 12 volt batteries for three minutes.

At the end of three minutes and while the battery is still on fast charge, test the voltage of each cell with the voltmeter of the battery-starter tester or a reliable moving coil test voltmeter.

The cell voltages must balance within 0.1 volt. If the variation in voltage is greater than 0.1 volt, the battery is defective and must be replaced.

If the cells are balanced within 0.1 volt, test the TOTAL VOLTAGE of the battery while it is still on fast charge. If the voltage of a 6 volt battery is over 7.75

volts, or the voltage of a 12 volt battery is over 15.5 volts, the battery is probably sulphated and must be given a slow restoring charge, and then re-tested for capacity. If the second capacity test is satisfactory, the battery is serviceable; if not, it requires replacement.

If the battery voltage is less than 7.75 volts or 15.5 volts after three minutes of fast charging, the battery condition is good and charging only is needed. The battery can be left on fast charge and with thermostatic protection as provided in Crypton Fast Chargers, will take a fast charge satisfactorily and will be recharged without overheating or excessive gassing in an average if 30 to 60 minutes.

When making the charge-test, it is important to see that the battery is warm. The temperature of the battery must be at least 60 F.

If any water has been added to the battery to bring up the electrolyte level, the battery must be left on charge sufficiently long to ensure that the electrolyte is thoroughly mixed before the cell voltage readings are taken.

CHARGING SULPHATED BATTERIES

It is important that sulphated batteries are charged at a low charging rate for a long period. In most cases the owner will need to be provided with a loan battery because at least 24 hours will be required for recharging. While the battery is being charged the specific gravity of all cells should be checked hourly and when the specific gravity ceases to rise for three consecutive hours, the battery is charged. A further test should then be made of battery capacity and if the voltage is higher than 4.8 volts or 9.6 volts the battery is suitable for continued service. If, however, the battery does not read 4.8 or 9.6 volts, a replacement battery is required.

PREVENTING BATTERY SULPHATION

The only way to prevent batteries from becoming sulphated is to keep them in a fully charged condition. This involves:-

(1) Keeping the batteries in a cool place.

(2) Charging the batteries systematically at regular intervals to keep them fully charged.

(3) Making a check of all batteries on all cars before they leave the service station to ensure that they are in good condition and not likely to cause early starting trouble.

It is particularly important to see that the batteries on cars which are sold are in good condition, otherwise new and used car customers will come back with serious complaints of having been sold a car with a deficient battery. It is also good business to see that no serviced vehicles leave the shop with batteries which are less than fully charged, because this may give rise to trouble and result in "come-backs" or - what is worse - the loss of customers.

OVERCHARGING.

Overcharging will seriously damage batteries and it is important to take the greatest care to see that batteries are always charged in the right way, at correct rates and the proper time.

A battery is considered charged when the sulphuric acid has left the plates and has entered the electrolyte. If the vehicle charging rate is too high because of a defective generator, or if a shop battery charger continues charging after the battery is charged, the charging current will decompose the water in the electrolyte and produce oxygen gas at the Positive plates and hydrogen gas at the Negative plates. The hydrogen gas is highly explosive and if sparks or flames are brought near the battery, an explosion can result. The oxygen gas is very active and unless dispersed, will combine with the grids and cause grid oxidisation, leading to ultimate failure. The grids will become weakened and active material will become dislodged. Internal short circuits develop which will reduce the capacity of the battery.

Overcharging sometimes results from long journeys at high speed in hot weather. The battery will function satisfactorily whilst the starting and lighting loads are light but when cold weather conditions are experienced, and the starting load increases, the battery will fail.

FAST CHARGING

Fast battery charging has become understandably popular because of its simplicity and controlled safety. The correct term for fast charging is really "battery boosting" because the battery is not actually fully charged. It is usually charged to about 90 per cent. of its capacity, the remaining 10 per cent. being furnished by the generator when the vehicle is running.

Modern fast charging should be considered from the aspect of battery testing as well as charging and the ideal arrangement is to use with the Fast Charger a modern Battery Open Circuit Voltage Tester and a Battery - Starter Tester. The combination of these two instruments with a Fast Charger, covers every requirement in good battery servicing.

The Basic Steps in Battery Servicing.

When a vehicle comes in with battery trouble or in cases where a battery is tested on a vehicle in the shop, the first test made should be to check the state-of-charge with an open circuit voltage tester. This will immediately show the state of charge of each cell.

A second test should then be made by testing the battery capacity with a Battery-Starter Tester. If the battery passes the test it can be put back into service. If it does not pass the capacity test, it should be given a charge-test.

This charge-test will give two important items of information, Firstly, it shows the similarity of the cell voltages under charge and secondly, the voltage of the battery under charge.

If, after three minutes fast charging, the cell voltages vary more than 0.1 volt, the battery is definitely defective and must be replaced.

If the cell voltages are uniform within 0.1 volt and the battery overall voltage on fast charge is less than 7.75 for 6-volt or 15.5 for 12-volt batteries, it can be safely fast charged with a suitably designed Fast Charger such as the Crypton "Chargemaster" which has thermostatic control to protect against any undue rise in battery temperature and also automatically terminate fast charging at the proper time.

If, after three minutes fast charging, the battery voltage is higher than 7.75 volts or 15.5 volts, the battery is sulphated and must be given a slow restoring charge.

With this modern approach to battery testing and charging, it is possible in less than five minutes to get all the information needed about the battery-state-of-charge, capacity and condition. In less than one hour a battery in satisfactory condition can be charged.

The Advantages of a Battery Testing Programme.

The availability of a modern Fast Charger, an Open Circuit Battery Tester and a Battery - Starter Tester, enables a complete programme of battery servicing to be operated under conditions which will be highly profitable, both in turnover and nett profits. The advantages are:-

(1) More batteries will be sold because a regular system of testing will disclose defective batteries before they actually fail on the vehicle. This is a service appreciated by most customers. Some may be doubtful and fail to accept the recommendation for a battery replacement. But - when the battery fails shortly afterwards, they realise how wrong they were to doubt the word of the service operator.

(2) More battery charging is sold, both fast charging and the slow restoring charging of sulphated batteries.

(3) The need of electrical service is shown by the condition of the battery and this sells additional service and parts such as fan belts, battery cables, regulator replacements, generator repairs and replacements and starting system service.

(4) Time is saved and costs are lowered because customers can be told in less than five minutes whether their battery is good or bad, whether it requires fast charging or is sulphated and needs corrective slow charging.

(5) Profits are increased because a large proportion of batteries can be safely fast charged in the vehicle. This saves labour time and eliminates the need and capital costs of loan batteries.

(6) "Slave" batteries are also reduced because modern Fast Chargers are also emergency engine starters. They enable vehicles to be started from the A.C. mains in one to two minutes.

Remember that by far the largest proportion of battery troubles is due to sulphation. As we have seen, this is caused by not keeping the battery fully charged. A properly operated battery testing and charging programme will solve this problem and enable every battery in stock to be kept in a fully charged condition and every vehicle which leaves the service shop, go out with a sound and fully charged battery.

It must be remembered that sulphated batteries need to be charged at a slow rate for a long period. This requires the use of a standard type Shop Charger, either of the metal rectifier or valve rectifier type.

THE CRYPTON COURSE
OF
ENGINE AND ELECTRICAL SERVICING

LESSON 14

CATHODE RAY OSCILLOSCOPES

CRYPTON EQUIPMENT LIMITED
BRIDGWATER — SOMERSET — ENGLAND

CATHODE RAY OSCILLOSCOPES

During recent years important developments have been made in the application of Cathode Ray Oscilloscopes for Engine Testing. The use of these Oscilloscopes has opened up an entirely new method of engine testing and fault diagnosis.

The Cathode Ray Oscilloscope is basically similar to a television receiver. It uses the same basic type of electronic circuit and incorporates a similar type of tube. It gives a 'picture' of what is happening in the engine by showing the changes in the ignition characteristics of the engine as they actually take place. We can see on the "television screen" when the spark takes place, the voltage of the spark, the opening and closing of the distributor breaker points, the action of the condenser and exactly what is happening at any speed in the entire ignition system.

The Cathode Ray Oscilloscope is inherently simple, both to connect and operate and it accurately portrays in the form of a pattern or "trace" what is taking place in the ignition system. At first sight the pattern appears complicated and operators who use the Oscilloscope must study the pattern and get an understanding of what it means. This isn't difficult and if the effort is made, the operator will soon grow accustomed to the pattern or trace and be able with remarkable speed and accuracy to check ignition condition and diagnose the cause of any trouble.

The first requirement is to get a clear understanding of the basic principles of the Cathode Ray Oscilloscope; it is necessary to understand how it works, what kind of "pictures" we shall see on the screen, what these "pictures" mean and how we can use them to make a thorough test of the ignition system.

THE BASIC PRINCIPLE OF THE CATHODE RAY OSCILLOSCOPE

A convenient way of getting an understanding of the basic principles of the Cathode Ray Oscilloscope is to consider an ordinary electric lamp, connected through a switch to an alternating current supply of 240 volts at a frequency of 50 cycles per second. When we look at the lamp filament we will see that it glows at an apparently constant brilliance and will go on doing so as long as the switch is closed and the supply mains voltage does not vary.

Now - the important point to remember about the lamp is that although the brilliance of lighting appears constant, the current flowing through the lamp constantly varies; it changes from zero to a maximum value in one direction, then reverses to zero and grows to a maximum value in the opposite direction.

If we now take the same lamp and connect it to a direct current mains electricity supply of 240 volts, we will find that the lamp will light in exactly the same manner and will have the same brilliance. In this case, however, the flow of current through the lamp filament is constant and in the same direction all the time.

We see from the above examples that the brilliancy and apparent constancy of the lighting of the lamp does not indicate whether it is used on alternating

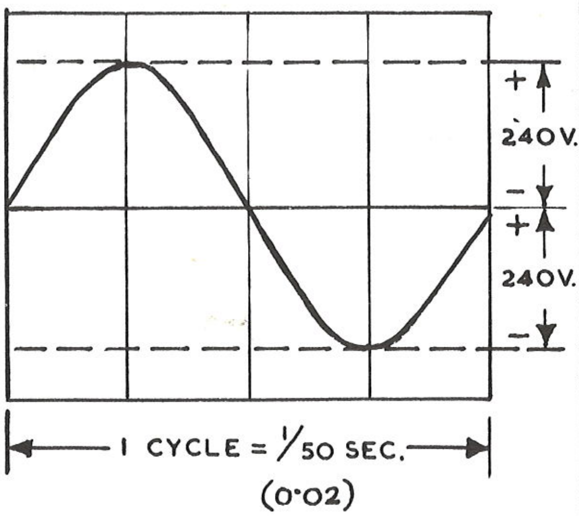


FIG: 1.

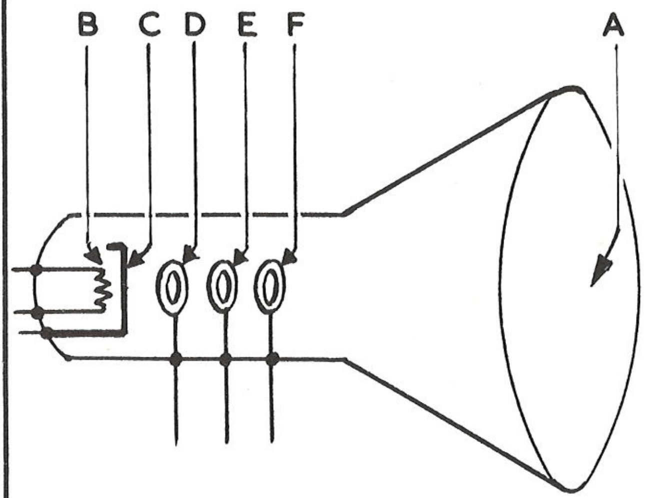


FIG: 2.

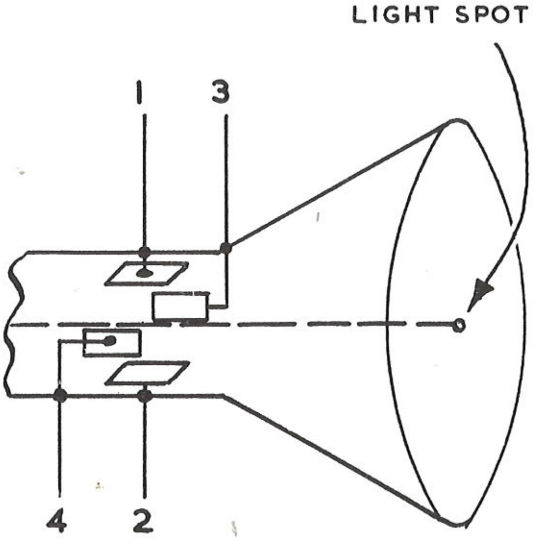

LIGHT SPOT
1
3
4
2

FIG: 3.

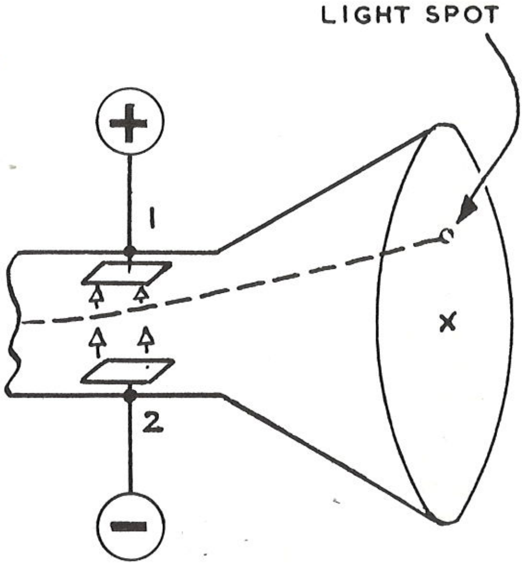

LIGHT SPOT
+
1
X
2
−

FIG: 4.

current which is continually changing both in value and direction of flow, or direct current which is constant both in value and direction. All the lamp does is to show by the brilliancy of its lighting that the voltage of the two systems is the same and is being maintained at a constant level.

If we take a standard type of ammeter or voltmeter and connect the instrument firstly to an alternating current supply and then a direct current supply, the same kind of thing will happen. We shall not be able to tell from the meter reading itself whether the supply is alternating current or direct current. In other words, we have no means of measuring either if the current is continuously varying in value and direction. To measure variation and direction we must find a method which shows firstly the change in the value of the current flowing and also the direction in which it flows.

What happens in the alternating current system is shown in Fig.1 which shows the variation in voltage values and direction in a normal 240 volt alternating current supply system. The voltage starts at zero, gradually increases to 240 volts in a Positive direction and then falls to zero. It then reverses and increases to 240 volts in the Negative direction and again returns to zero.

This process of rising from zero to a maximum in the Positive direction, reversing to zero and then growing to a maximum in the Negative direction, again returning to zero, is called a cycle.

The cycle consists of the two voltage surges shown in the diagram - it is the complete change of voltage from zero to maximum positive and through zero to maximum negative and back to zero again.

When there are fifty complete cycles occurring in one second, it is called a "50 cycle supply". The length of time for a single cycle is 1/50th second. The name "frequency" is given to the number of cycles per second, i.e., we say the system has a frequency of 50 cycles. Alternating current systems throughout the world have different frequencies - for example, in the United States the standard frequency is 60 cycles, in some countries there are 40 cycle supplies.

The instrument which will respond to the rapid changes, both value and direction, which take place in an alternating current supply system is the Cathode Ray Oscilloscope. This instrument measures both the value and rapidity of the changes which take place by a moving spot of light which has no time-lag or inertia and will respond with exactly the same rapidity as the changes in the electrical voltage. The moving spot of light shows by a graph or pattern on a glass screen, the instantaneous changes in voltage, polarity and time, exactly as they occur in the circuit to which the instrument is connected. If the Cathode Ray Oscilloscope is connected to a 240 volt alternating current supply the light trace will be as in Fig.1, showing instantaneously what is happening in the alternating current system while it is happening.

THE PRINCIPLE OF THE CATHODE RAY OSCILLOSCOPE

The measuring unit of the Cathode Ray Oscilloscope is a "television tube" as seen in Figure 2. The tube is made of glass, evacuated to a high standard of vacuum and the inside of the front face or screen "A" of the tube is coated with a special flourescent substance which glows visibly under certain conditions. At the end of the tube is a filament "B" which is basically similar to the filament

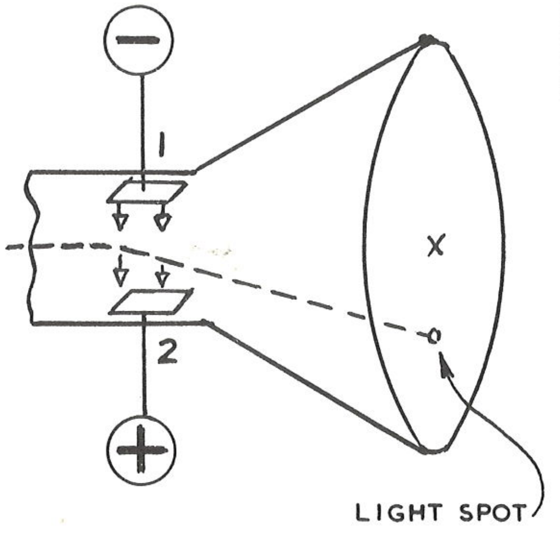

1
2
LIGHT SPOT

FIG: 5.

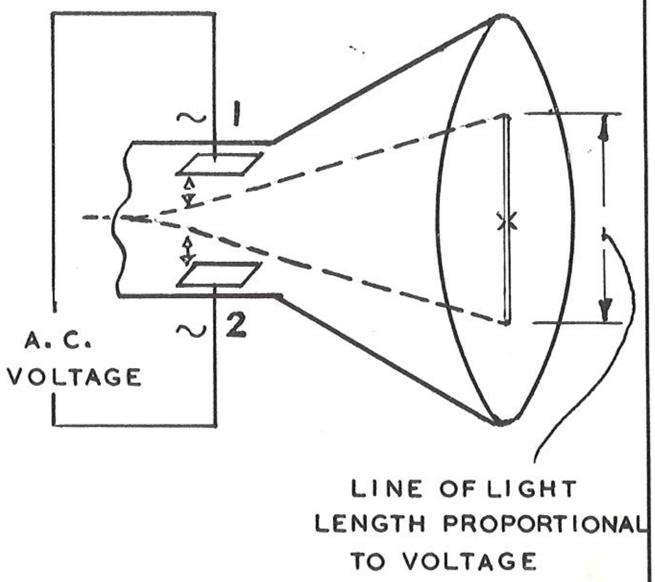

1
2
A. C.
VOLTAGE
LINE OF LIGHT
LENGTH PROPORTIONAL
TO VOLTAGE

FIG: 6.

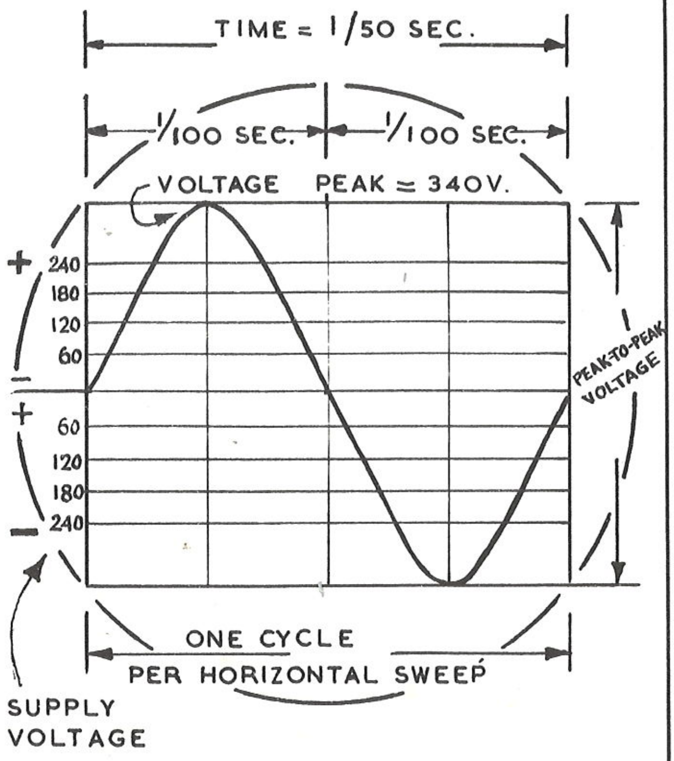
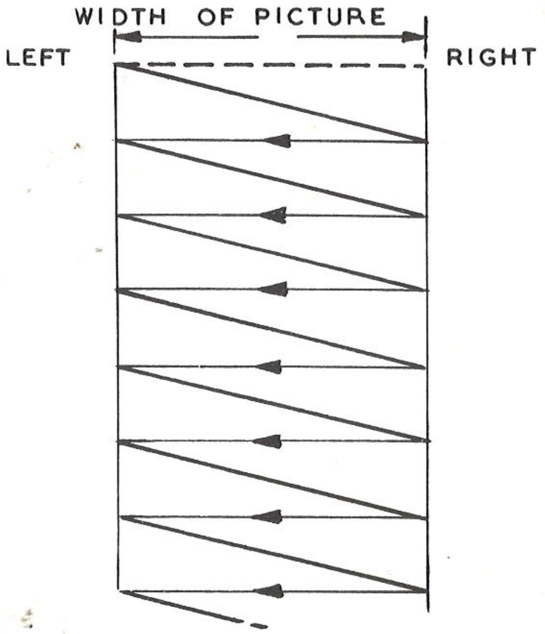


FIG: 7.


WIDTH OF PICTURE
LEFT
RIGHT

ILLUSTRATING HORIZONTAL "FLY-BACK" OF LIGHT SPOT

FIG: 8.

of a lamp bulb and is heated by a low voltage supply from a power pack incorporated in the Oscilloscope. Adjacent to the filament is a cathode "C", an active element which, when heated by conduction from the hot filament "B", emits large quantities of negative particles of electricity or electrons.

Along the neck of the tube are a number of control elements shown at "D", "E" and "F". They are connected to the positive side of a source of high direct current voltage supplied through a power pack which forms part of the Oscilloscope.

When the Cathode Ray tube is switched on the filament "B" is heated by the current flowing through it and will heat up the cathode "C" which then has the property of emitting large numbers of electrons. When the control elements "D", "E" and "F" are positively charged, at a high voltage, they attract the free electrons emitted by the cathode and these electrons travel at high speed towards the elements. The same kind of thing happens as when a magnet attracts iron filings towards it, the difference being that in the case of electrons there are many many millions travelling at tremendously high speed. The control elements condense the high speed stream of electrons into a narrow beam - like the beam of a sharply focussed lamp - and also greatly accelerates the speed of the electron flow.

The electrons pass through the openings in the elements and impinge on the inner surface of the front screen of the cathode ray tube. This causes the flourescent material to glow brilliantly at the spot where the beam strikes, and a brilliant spot of light appears on the screen.

This beam is the "cathode ray" and is similar to a ray of light with one important difference. It is similar to light in the fact that it has no weight or inertia but differs from a beam of light in being susceptible to electric charges or magnetic fields. The cathode ray can be bent or deflected if it is subject to electric charges and magnetic fields. This makes it possible to move the ray and the light spot in response to electrical influences. The movement of the light spot will show the extent and value of the electrical influences, no matter at what speed they occur.

Figure 3 shows graphically how this is done. The diagram shows the same tube as in Figure 2, but we now see a group of four deflector plates, Nos. 1 and 2 located above and below the line of the cathode ray and Nos. 3 and 4 to the right and left of the cathode ray. The elements are sealed in the tube and connections are brought out through the neck of the tube and attached to external electrical circuits by means of a multi-plug insulated cap on the tube which fits into a corresponding socket.

If we examine Figure 4 we will see that Plate 1 in the tube is positive and Plate 2 negative. When the cathode ray - which is composed of negative particles of electricity - passes through the two plates the ray will be attracted towards the positive plate No.1 and repelled from the negative plate No.2. The extent of the movement towards Plate No.1 will be in proportion to the voltage applied. This is shown in the diagram where we see that the ray is deflected upwards and the light appears towards the top of the screen as shown.

When the polarity of the plates is reversed and Plate No.2 becomes positive, the reverse action takes place. The cathode ray and light spot will be deflected towards Plate No.2 and repelled from Plate No.1. The light spot will now be in the position shown towards the bottom of the screen.

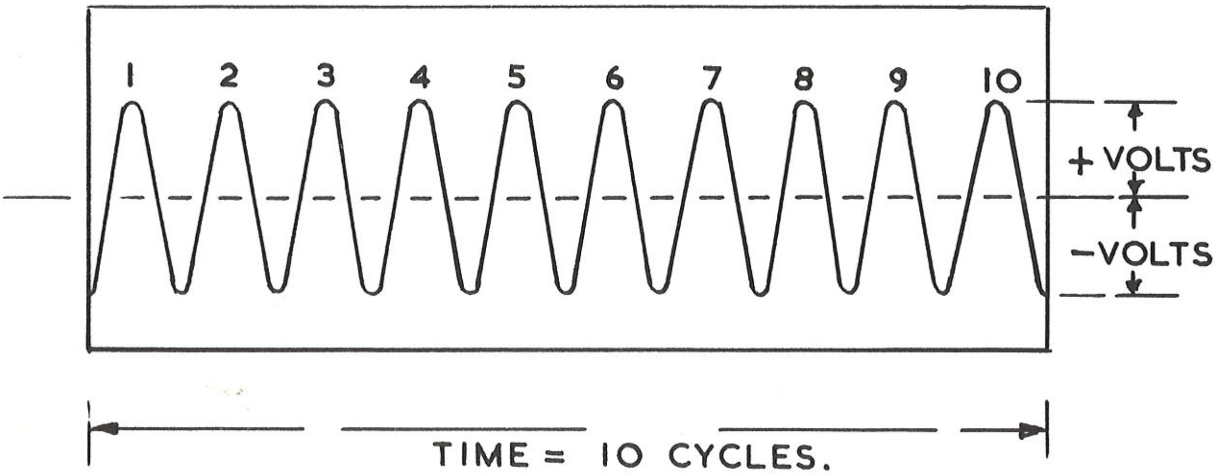

1
2
3
4
5
6
7
8
9
10
+ VOLTS
−VOLTS
TIME = 10 CYCLES.

FIG: 9.

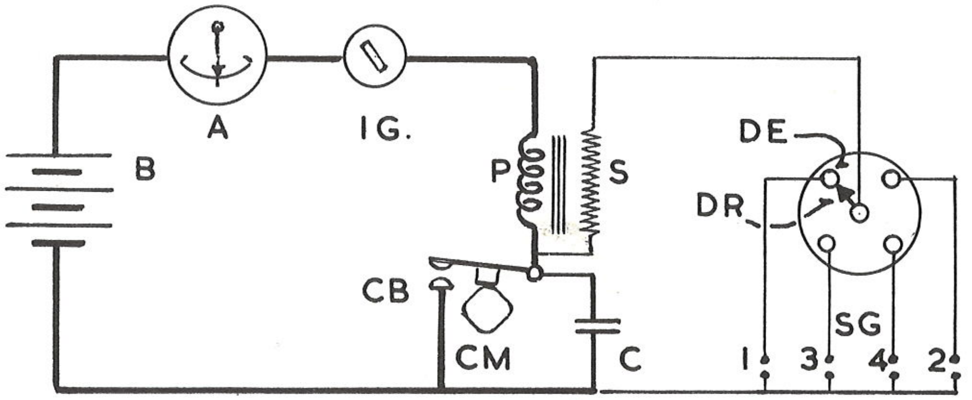

A
IG.
B
P
S
DE
DR
CB
CM
C
SG
1
3
4
2

FIG: 10.

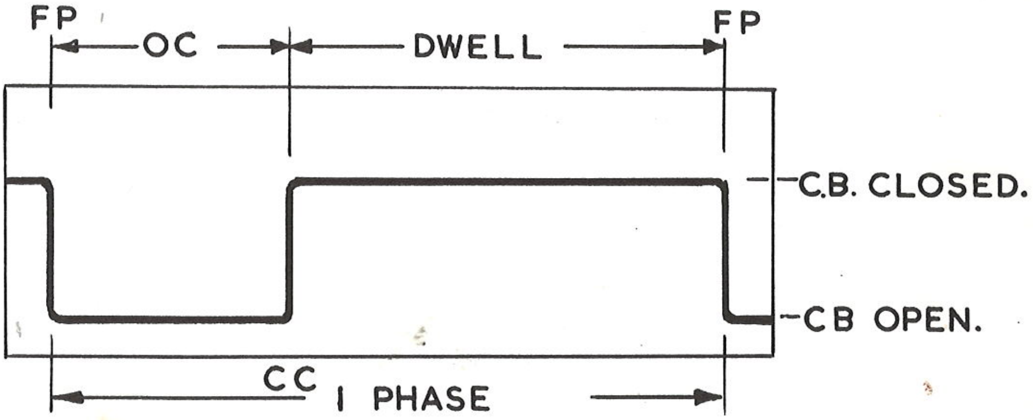

FP
OC
DWELL
FP
C.B. CLOSED.
CB OPEN.
CC
1 PHASE

FIG: 11.

When no voltage is applied to either of the two plates the spot will be in the centre of the screen as shown by the cross in Figures 4 and 5.

If the two plates are connected to the terminals of an alternating current supply mains each will become positive and negative in turn and the light spot will move up and down in the form of a vertical line. If the supply frequency is 50 cycles per second there will be fifty movements of the light per second. We shall see on the screen a vertical line of light, the length of which above and below the central zero position, being in proportion to the value of the voltage. Thus, we have a means of actually measuring the rapidly changing value of the voltage and literally seeing the voltage changes as they take place.

Time

In practice we have to deal with the question of time as well as voltage and it is for this purpose that the remaining Plates 3 and 4 shown in Fig. 3 are used.

The same principle is used of applying a positive and negative voltage to the two plates. When Plate No.4 is positive the ray will be attracted towards the reader and when Plate No.3 is positive the ray will be attracted away from the reader.

To obtain a trace of a single cycle of a 50 cycle alternating current supply a deflecting force is applied to Plates 3 and 4 so that the polarity changes completely in one fiftieth of a second. When Plate 4 is fully positive the spot will be towards the reader and when its polarity has changed to fully negative with Plate 3 becoming positive, the spot will be fully away from the reader. The light spot will actually travel from the left to the right of the screen in a straight line in exactly one fiftieth of a second.

Tracing Time and Voltage Simultaneously

If an alternating voltage is applied to Plates 1 and 2, and at the same time a deflecting force to Plates 3 and 4, the screen will show the change both in time and voltage. The light spot will still travel across the screen but not in a straight line. It will be deflected upwards and downwards according to the polarity and value of the alternating current voltage and to the right or left of the screen, according to time. The result will be a pattern or "trace" as shown in Figure 7. The vertical plates move the beam up for the first half of the alternating cycle to a maximum of approximately 350 volts, then back to zero and down for the second half of the cycle. We have a picture of the current flowing in the circuit, first in one direction and then in the other.

If we connect a voltmeter to the same circuit as in Figure 7, the instrument will not be able to follow the rapid fluctuations of the alternating current and will read a "mean" voltage of 240 volts which is the voltage of the system.

In an alternating current supply one cycle of alternation is immediately followed by another and there are fifty complete cycles every second. If the beam traversed the screen in one fiftieth of a second, we should get a line of light depicting one cycle only. This would take place too quickly for the eye to follow. To enable a sequence of cycles to be indicated it is necessary to modify the horizontal traverse and this can be done in one of two ways.

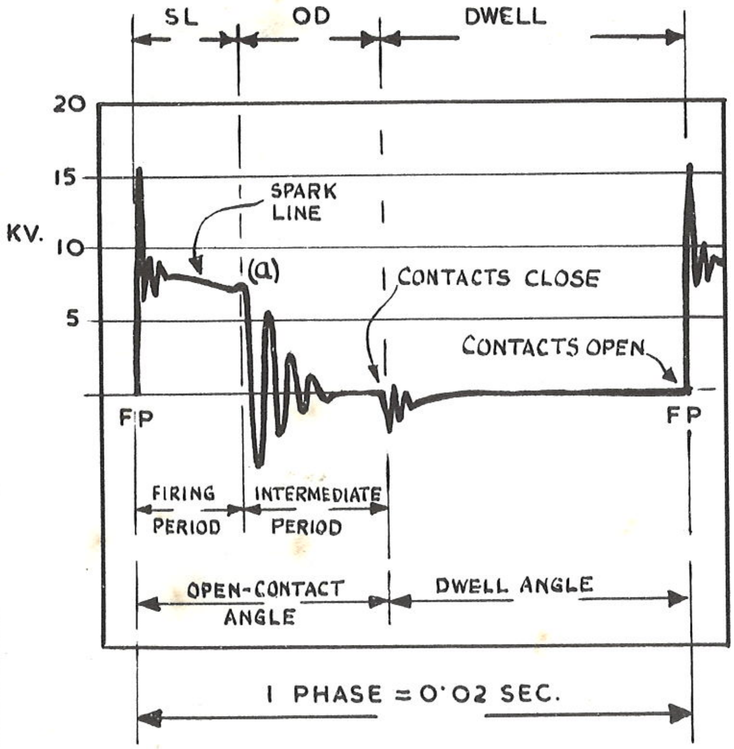

SL
OD
DWELL
20
15
10
5
KV.
SPARK LINE
(a)
CONTACTS CLOSE
CONTACTS OPEN
FP
FP
FIRING PERIOD
INTERMEDIATE PERIOD
OPEN-CONTACT ANGLE
DWELL ANGLE
1 PHASE = 0·02 SEC.

FIG: 12.

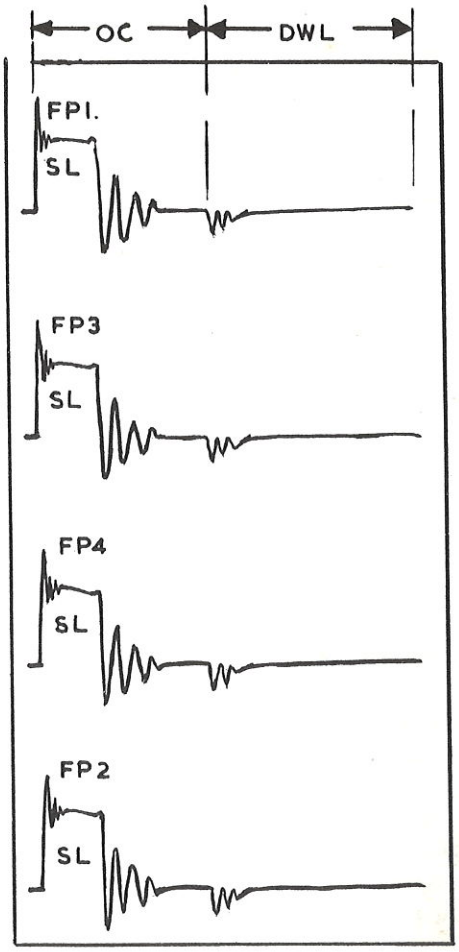

OC
DWL
FP1.
SL
FP3
SL
FP4
SL
FP2
SL

FIG: 14.

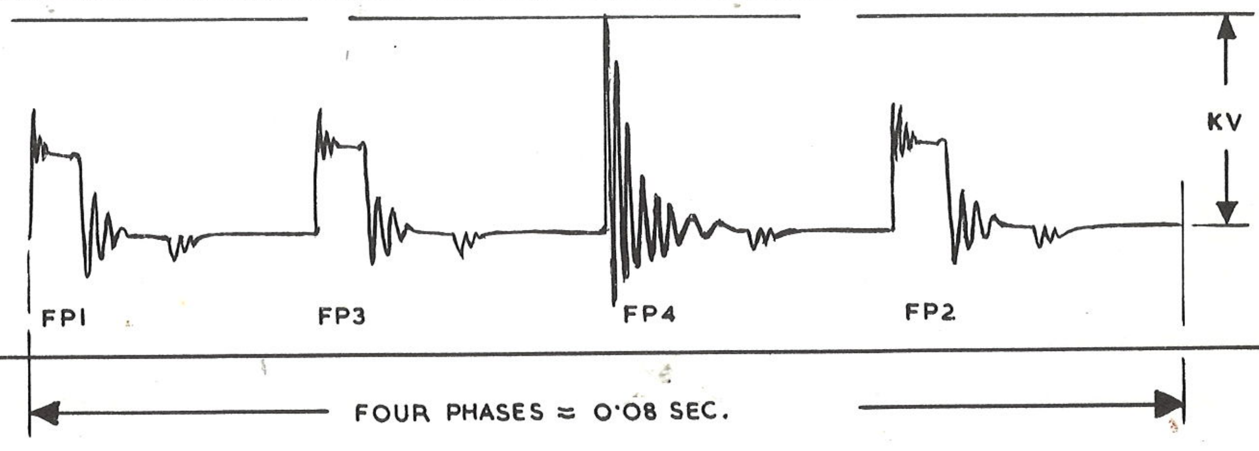

KV
FP1
FP3
FP4
FP2
FOUR PHASES ≈ 0·08 SEC.

FIG: 13.

(1) Slow down the rate of movement across the screen so that several cycles would occur and show their trace in a continuous line.

(2) Arrange to "flick" the light spot back instantaneously so that the beam sweeps back and forth across the tube space and will start tracing the voltage curve of the second cycle immediately the first is completed.

In practice both these methods are combined as we shall see in the following example:

Instead of the beam traversing the screen in one fiftieth of a second we will slow it down so that it takes one fifth of a second. This means that we now see ten complete voltage cycles in sequence. In addition the spot is flicked back at the end of the tenth cycle, so that it will be on the left of the screen in time for the commencement of the eleventh cycle. The resulting trace will now show continuous groups of ten cycles following each other at one-fifth second intervals.

Figure 8 illustrates the effect of the flicking back or fly-back of the spot at the end of the horizontal trace. If a card is placed over the diagram with its top edge in line with the top broken line, and is then drawn steadily downwards, the black line will appear to move in exactly the same way as the light spot travels across the screen. The movement from right to left is so rapid as to be virtually timeless.

Figure 7 shows the kind of picture we would see if the time trace or "horizontal sweep" is adjusted to synchronise with mains frequency, i.e., one-fiftieth of a second. The vertical deflection due to voltage and polarity changes and the horizontal sweep synchronised with time, gives us the curve shown which, it will be noted, corresponds with the basic diagram we saw in Figure 1. In Figure 9 we see a trace of ten cycles in succession on a horizontal sweep of 0.2 seconds.

The above examples show the complete information which an Oscilloscope trace reveals on a simple application like the standard A.C. mains wave form. The voltage and frequency can be measured by the height and length of the trace and the exact rate of voltage rise and fall can be seen. By using various control circuits the beam can be made to travel longer or shorter distances for a given voltage or time interval. The flexibility of application which is provided enables the Oscilloscope to be applied for a vast number of extremely accurate testing purposes.

THE VALUE OF AN OSCILLOSCOPE FOR IGNITION TESTING

Before we consider how the Cathode Ray Oscilloscope is applied for the measurement of the rapid changes which take place in vehicle electrical systems, it must be appreciated that the Oscilloscope cannot fully replace instruments for ignition testing. The great value of the Oscilloscope is that it shows conditions which existing instruments cannot indicate, such as the firing voltage, ignition coil voltage and voltage changes at the plug terminals. Instruments will, however, show conditions which the Cathode Ray Oscilloscope cannot indicate such as automatic advance, ignition timing and carburettor air-fuel ratio. For these reasons the Oscilloscope should be considered as supplementary to existing test instruments and not as a replacement of them. The important factor is that the use of an Oscilloscope adds considerably to the facilities of present testing instruments, giving them something they lack at present without overlapping or rendering obsolete any of their functions.

In considering the application of the Oscilloscope for ignition testing, the first thing to recognise is that we are dealing with the same kind of phenomena as we have already examined - a rapid variation of voltage and polarity in the ignition system.

Our basic need is to obtain a trace on the screen of the voltage changes which occur at the sparking plug terminals. This is the end-result of the operation of the ignition system, the whole purpose of which is to deliver the correct high tension voltage at all spark plugs.

BASIC PRINCIPLES OF CATHODE RAY IGNITION TESTERS

To measure the voltage changes which take place at the plug terminals of the engine, two deflecting impulses are needed. The first of these is the voltage rise and fall which can be displayed as a vertical displacement of the beam on the cathode ray screen. The second is a time-base displacement which takes the form of a special alternating voltage applied to the horizontal plates which must sweep the electron beam at a constant rate from left to right and then quickly return the beam to the left side of the tube to begin the next trace. The horizontal sweep must show single or multiple phases and must be triggered to synchronise with the speed of the engine and therefore with the "sequences of ignition phases."

What we mean by ignition phases will be clear from a study of Figure 10. In this diagram "B" is the battery which supplies current through the ammeter "A" and ignition switch "IG"to the coil primary "P", from whence it flows via the distributor breaker points "CB" to earth and back to the battery. The breaker points "CB" are bridged by the condenser "C". The high tension voltage generated in the coil secondary winding "S" flows via the distributor rotor "DR" and electrodes "DE" through the H.T. cables to the spark plugs "SG".

When the contact breaker points "CB" are closed, current flows through the coil primary winding "P" via the ammeter and ignition switch. Each time the lobe of the distributor cam "CM" opens, a high voltage surge is set up in the coil secondary winding and applied through the distributor rotor to one of the four spark plugs. The electrode of the rotor is timed to be in line with the distributor electrode connected to the plug in the cylinder next due to fire, so that the spark jumps the distributor gap and the gap of the spark plug concerned at the instant of contact breaking. The four spark plugs fire in timed sequence as the four cam lobes lift the rocker in turn and the rotor aligns with each distributor electrode and directs the spark energy to the correct plug in rotation.

There are four firing points in each rotation of the distributor cam and we therefore have four ignition phases, during each of which a number of electrical changes occur in the circuit. Some of these changes can be measured with measuring instruments, but others can be seen only on an Oscilloscope.

Figure 11 is a graphic illustration in its simplest form of the characteristics of an ignition phase. Starting at the point "FP" the primary current falls to zero when the points open and remains at zero until the points close again at "CC".

The primary current then rises to a value determined by the resistance of the circuit and remains at this value while the points are closed, falling again to zero when the contacts open at the second "FP" position. The ignition phase extends from the first "FP" to the second "FP" position and is divided into two sections, (1) the open contact "OC" section when the contact points are open and secondly the "DWELL" section when the contact points are closed.

Because of the importance of getting a proper understanding of ignition phases, let us check it over once again. Immediately the contact points open the primary current falls to zero and remains at zero while the points are open. When the points close the current grows to a value determined by the resistance of the circuit and remains at this value while the points are closed. The time for which the points are closed is called the "DWELL" angle or "CAM" angle and can be expressed in terms of the number of degrees of rotation of the distributor cam while the points are closed.

A lot of things happen, however, in the ignition phase in addition to the simple rise and fall of the primary current as shown in Figure 11 and are graphically illustrated in Fig.12. At first sight the diagram will be difficult to understand but, if it is examined in detail, it will be seen that it shows exactly the variation in voltage which takes place in the ignition system during a complete ignition phase.

The voltage pulses which take place in the ignition system are applied through special circuits to the two vertical deflector plates in the Oscilloscope tube (Nos. 1 and 2 in the simple diagram in Fig.3). Simultaneously a horizontal deflection voltage or "time-base" voltage is applied to the horizontal deflecting plates and is so arranged that the beam travels across the screen in the time taken to complete one ignition phase, i.e., from one firing point to the next; it then flicks back in readiness to continue the trace of the next phase. If a horizontal sweep of 0.02 seconds is used in the example we have previously considered, one complete ignition phase will be displayed across the screen when the tube is connected to the ignition system of a 4-cylinder engine running at 1500 R.P.M. and this trace will remain synchronous so long as the engine speed is constant. Figure 12 shows a typical pattern or trace obtained under these conditions and shows vertically the change in the ignition system voltage and horizontally the time during which the voltage changes occur.

Each wave form relates to a particular cylinder and is relatively independent of the preceding or following form waves. In order to identify specific cylinders there must be a fixed reference point which is always available and easily recognised. This is the left side or the beginning of the horizontal trace. By triggering the horizontal sweep circuit when a particular plug fires the first wave form will always be in a constant relationship to the triggering plug, the remaining wave forms following in the firing order of the engine.

A comparison between Figure 12 and Figure 11 will show the similarity between them and to make this easier the same letter indications are used. The length of the phase is the same in both diagrams as shown by the letters "FP". The "OC" and "DWELL" sections are also shown by the same symbols.

Carefully examining Figure 12 we see that immediately the points open and the primary current falls, there is a sharp rise of secondary voltage at the point "FP" in Fig. 12. This voltage may be as high as 15 KV (15,000 volts) and is indicated on the vertical scale of the screen. This high voltage is delivered to the spark plug, ionises the gas particles in the plug gap, and causes an arc between the electrodes. Immediately this happens the voltage falls to the value required to sustain the arc across the plug electodes, and we see this fall in voltage and also the time duration of the arc in the part of the trace shown as "SL" (spark line) in Fig.12. As soon as the energy of the spark is expended and the arc between the plug electrodes is extinguished, the remaining energy in the ignition coil dissipates itself as an oscillating current, beginning at point (a) and gradually dying out as it approaches point "CC". This oscillation is due to the combined effect of the ignition coil and condenser in dissipating the energy which remains in the ignition coil when the spark is extenguished. The contact breaker points close again at point "CC" in Fig.12. The closing of the points causes a second and smaller oscillation, due to the building up of the coil primary current. These oscillations quickly decline to zero until the next "FP" point is reached, when the points open again.

In analysing the oscilloscope pattern it is convenient to divide the complete pattern into three periods (1) the firing period, (2) the intermediate period and (3) the dwell period. These are shown in Fig.12. The firing period covers the duration of the spark at the spark plugs, the intermediate period the dissipation of theenergy in the coil, and the dwell period the building up of the ignition energy for the next spark.

When the horizontal base is synchronised with the duration of one ignition phase, as shown in Fig.12, each new phase is superimposed on the preceding one and the picture shows the average shape of the ignition voltage curves. Any irregularity which occurs in one cylinder only cannot easily be singled out. This is made possible, however, by a special adjustment which slows down the operation to one revolution of the distributor cam. We now obtain a continuous trace of all the cylinders in the engine, such as seen in Fig. 13 for a 4-cylinder engine, and a faulty condition in any one cylinder becomes immediately visible.

This is illustrated in Fig.13, where it will be noted that one of the patterns is different to others. This is No.4 in the diagram where the curve rises to a higher firing point, there is no firing period and the oscillations are wide and rapid. It is obvious that there is a deficiency in the cylinder and the cause can be accurately diagnosed by a correct interpretation of the pattern.

The first point to note is that we can see immediately the cylinder in which the defect is occurring - this in itself is a big step forward. The next point to note is that the high peak voltage with no following spark voltage (as is shown in Fig.12) clearly shows that no spark is taking place at the plug. If a spark did take place we should have the peak firing point followed by the lower spark voltage as seen in the patterns for the other cylinders. We can, therefore, safely deduce that a break has occurred in the high tension connection to the plug. The reader can check this for himself at any time, merely by removing one cable from a plug, when the effect obtained will generally be similar to that shown in Fig.13.

The identity of the cylinder in which the fault occurs can be found from its position in the pattern. If the horizontal trace is triggered to commence with the firing point of No.1 plug, and the engine has a firing sequence of 1-3-4-2, the faulty cylinder will be No.4 as shown in the diagram.

ANALYSING THE PATTERN

The key points in the Oscilloscope pattern are the firing point and spark voltage. The height of each firing point indicates the firing voltage for a particular cylinder and the height at the beginning of the spark voltage line and the extent of the oscillations in the line, indicate the resistance conditions in the high tension circuit. The higher the spark voltage and the greater the oscillations, the higher the resistance present.

The height of each firing line depends upon conditions existing within the cylinder or in the secondary circuit of the ignition system and the important point to note is firing voltages which are higher than normal.

These can be caused by the following troubles:-

Inside the Cylinder - wide plug gaps ... worn plug electrodes ... lean air-fuel ratios ... high compression pressures.

Outside the Cylinder - broken H.T. wires ... defective distributor cap ... wide rotor gap ... incorrect H.T. connections.

Where the pattern shows a higher than normal spark line and excessive oscillations it indicates excessive resistance. This can be due to burned or corroded H.T. connections or defective suppressor resistance.

In analysing the intermediate period pattern, the oscillations should disappear or nearly disappear by the time the points close and the dwell section begins. If the oscillations are short and only one or two oscillations are visible in the pattern, it indicates trouble such as a leaky condenser, short circuited coil or a partial short circuit in the distributor primary circuit.

The commencement of the dwell period is shown in the pattern by a short downward line followed by rapidly diminishing oscillations as clearly shown in Fig.12. Each oscillation should be shorter than the preceding one and if this is not the case and the second oscillation is greater than the first, it indicates poor contact point condition or unsatisfactory point closing. Excessive arcing at the points when the breaker points open will be seen by an oscillatory pattern just before the points opening position at the second "FP" position in Figure 12.

TYPES OF OSCILLOSCOPES

Two basic types of Oscilloscopes have been developed. One can be called the "In-Line" or "Series" type, where the pattern follows the lines illustrated in Figures 12 and 13. In this design, patterns of either single phase, as shown in Figure 12 or a number of phases as shown in Figure 13 can be obtained, the multi-patterns following each other.

The second type of Oscilloscope has basically similar patterns but the phases are displayed one below the other. This allows each of the traces to be examined in detail and the intervals of open circuit and dwell periods to be directly compared.

Both types of Oscilloscopes have certain advantages and disadvantages but in each case the operating principle and basic methods of application and interpretation are the same.

THE RELATIONSHIP BETWEEN OSCILLOSCOPES AND METERS

Whilst the Oscilloscope is comparatively new in the field of automotive testing, it has been in general use for many years in laboratories and for radio and television servicing.

The Oscilloscope does not replace test meters - it supplements them and makes them much more valuable.

The fundamental difference between Oscilloscopes and Test Meters is that the Oscilloscope is an overall indicator whereas Test Meters are special purpose instruments. The Oscilloscope gives an overall picture of the conditions in the ignition system whereas an Electric Tachometer makes a specific measurement of engine speed ... an Exhaust Gas Analyser of air-fuel ratio and a Distributor Dwell Tester of distributor dwell angle. The Oscilloscope in two or three minutes points out the need where it exists for the searching ability of test instruments in locating the exact cause of troubles, the existence of which have been so quickly and accurately shown by the Oscilloscope.

In modern service both Meters and Oscilloscopes have become essential for the fast and accurate testing needed today. Where both are available, every single requirement in testing can be carried out in the quickest and easiest way and with guaranteed accuracy. The Oscilloscope will show in a few minutes whether or not the ignition system of an engine is good. If the test shows that the system is good, no time will be wasted in hunting for trouble that doesn't exist. If, on the other hand, the Oscilloscope test shows that trouble exists, it proves the need for pinpointing meter tests.

One of the practical difficulties which has existed in the use of Oscilloscopes is the problem experienced by many service shops in making effective use of earlier types of instruments. This was largely due to the complications of Oscilloscope design. Firstly the screens used were extremely small and secondly, a large number of controls had to be operated. To the normal complications of understanding a very small pattern, the additional complications of confusing controls were added.

Present day Oscilloscopes are free from these limitations. Screens are larger and controls have been greatly simplified.

Like all other instruments, the Oscilloscope has both advantages and limitations. It makes some tests which cannot be carried out with ordinary meters such as a measurement of the high tension voltage at spark plugs. It gives an overall picture of the ignition system in a way not possible with any other test equipment. The fact that it indicates the "shape" of the voltage rather than its actual value is often a big advantage. The ease with which it will compare the firing voltage at the plugs enables a direct check to be made of ignition reserve. An adequate reserve of ignition voltage is extremely important in today's high compression engines.

Although the application of the Oscilloscope is so extensive, there are many measurements which can be more easily and quickly made with meters. Examples are engine speed, with an Electric Tachometer, dwell angle and dwell variation with a Distributor Dwell Tester and automatic advance measurements with a modern Auto-Advance Tester. The same remarks apply to other special instruments such as Compression Testers and Exhaust Gas Analysers.

The ideal in service is to have both the Oscilloscope and selected types of meters. The Oscilloscope provides a fast and accurate method of determining the general condition of the ignition system; it will point out quickly and accurately certain definite troubles and will localise other troubles which can be quickly pinpointed with test meters. The Oscilloscope certainly does not or cannot replace other test equipment. It should be considered complementary to present test meters, not a substitution for them - a fully equipped shop needs both.